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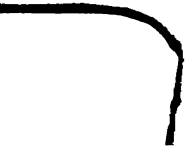

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Canadian Soc. Civ. & Scientific

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CV.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CONTENTS.

Sect. I.—MINUTES OF PROCEEDINGS.

3, 10, and 17 *March*, 1891.

	PAGE
Transfer of Associate Members to class of Members	1
Admission of Students	1
Election of Members, Associate Members, and Associate	1
"On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London." J. T. Harrison. (2 plates, 1 cut)	2
Appendix to ditto	25
Discussion on ditto. (2 cuts)	26
Correspondence on ditto. (1 cut)	87
List of rain-gauges, evaporation-gauges, &c., exhibited by the Royal Meteorological Society, in illustration of ditto	100
Resolution of sympathy with the widow and family of Sir J. W. Bazalgette, C.B., Past-President	106

24 *March*, 1891.

"The Reception and Storage of Refined Petroleum in Bulk." W. T. H. Carrington. (1 plate)	108
Appendix to ditto	118
Discussion on ditto. (1 cut)	119
Correspondence on ditto. (7 cuts)	137

Sect. II.—OTHER SELECTED PAPERS.

"The Construction of the New Nadrai (Kali Nadi) Aqueduct, Ganges Canal." W. Good. (1 plate, 3 cuts)	147
Appendix to ditto	160
"Effect of Temperature on the Strength of Railway Axles." Part III. T. Andrews, F.R.SS. L. & E.	161
Appendix to ditto	169
"Skew Arch Course Traces." F. Harris, B.A.	177

Digitized by Google

PAGE

"The Transmission and Distribution of Power from Central Stations by Compressed Air." Prof. W. C. UNWIN, B.Sc., F.R.S. (7 cuts) . . . 180
"The Manufacture and Properties of Slag-Cement." G. R. REDGRAVE . 215
Appendixes to ditto 226
"A Method of Constructing the Sub-Aqueous Part of Piers and Breakwaters with Soft Un-set Concrete." W. KIDD. (2 cuts) 231
Appendix to ditto 236
"Irrigation in Southern California, with Special Reference to the Artesian Wells in San Bernardino County." W. FOX. (2 cuts) 238
"Fire-proof Construction." J. J. WEBSTER. (3 plates, 2 cuts) . . . 249
Appendix to ditto 283
"The North Sea-Wall and Royal Albert Drive, Scarborough. W. ELIOT. (plate) 289
"Securing the North Cliff, Scarborough." R. AYTOUN. (plate) . . 295
"The Lanarkshire and Ayrshire Railways." W. A. P. TAIT, B.Sc. (*Abstract*), (1 cut) 298
Obituary 302
Sir Joseph William Bazalgette, 302; John Marley, 308; Loftus Perkins, 311; William Coupar Rennie, 314; Edward Slaughter, 316; Benjamin Walker, 317; Arthur Turnour Atchison, 320; Edmund Lincoln Harper, 323; John Jackson, 324.
List of Recent Deceases 325

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

A Cofferdam or Caisson without Timber or Iron in its Construction. R. L. HARRIS 327
Repairing the Foundations of a Bridge-Pier. C. B. HUNT 329
The Results of Deflection-Tests on Loaded Railway Bridges. E. PASCHEN 331
The Pollution and Self-Purification of Streams. F. P. STEARNS . . . 331
Report upon the Organisms, excepting the Bacteria, found in the Waters of the State (of Massachusetts) July, 1887 to June, 1889. G. H. PARKER 333
The Filtration of Water through Filters of calcined Infusorial Earth. Dr. H. NORDTMEYER 335
Chemical and Bacteriological Investigation of the Röckner-Rothe system of Sewage-Treatment at Potsdam. B. PROSKAUER and Dr. NOCHT . . 336
On the success attained by various systems of clarifying Sewage-Water at Frankfort-on-Main. Dr. B. LEPSIUS 338
The Schwartzkopff System of Sewage-Treatment (Berlin). B. PROSKAUER 340
The Disinfection of Dwelling-houses in the City of Berlin. H. MERKE . 341
Pastore's Water-Meter for Minimized Loss of Pressure. L. DECUGIS . . 342
Apparatus for the Prevention of the Waste of Water in Closets and from Taps. T. GOODSON 343
Pumping-Stations and Reservoirs lately erected for the Improvement of the Paris Water-Supply. — BECHMANN 344

Digitized by Google

PAGE
The Water-Supply of Brussels and its Suburbs. J. Gernaert . . . 347
Comparison of Water-Supply Systems from a Financial point of view. J. L. Fitzgerald 349
The quantity of Water available in Sandy Soils, and its utilization for the Supply of Towns. T. Stang 352
The Drainage of the Lake in the Tedingerbroek, Holland. P. A. Koreveaer 353
Works on the Marne and Saône Canal. A. Florentin 354
Hydraulic Work and Inland Navigation in Italy: Administrative Regulations and Methods of Construction. E. Manara 357
The Regulation and Maintenance of Inland Navigation in Italy . . . 360
The Abt Rack Railway. R. Audra 367
The State Railway on the West Coast of Sumatra. A. Kuntze . . . 370
Street Tramway in Berne, on the Mékarski System. A. Bertschinger . 373
Comparative Working-Expenses of Small Motors. C. Korte 375
Coke-Breeze as Fuel. G. Frère 381
The Utilization of Coke-Breeze. J. Pettré 383
The Coquerel Gas-Plant. G. Vitoux 385
On Lubrication with Mineral Oil. — Kuntze 386
Observations and Experiments on the Lubrication of Engines 387
Riveted Joints in Boiler-Shells. W. B. Le Van 388
Testing Steel Tires. E. Roussel 389
On Temperature Measurements in a Bore-hole at Sauerbrunn, in Bohemia. Dr. J. Puluj 390
The Florida Phosphate-Deposits. N. H. Darton 391
The Gold and Platinum Industry of the Ural. — Laurent 391
A New Process for the Treatment of Cobalt Ore. L. Pelleton . . . 396
On Desulphurizing Molten Cast-iron. P. Tunner 398
The Kassner Oxygen Process 399
New Electrolytic Method of Determining Metals. Edgar F. Smith . . 401
The Practical Aspects of Electric Welding. F. A. C. Perrine 403
The Direct Conversion of Heat into Electricity. R. J. Gülcher . . . 404
A Charge-Indicator for Accumulators. E. Hospitalier 406
Siemens Dynamo with Internal Field-Magnets. F. Drouin 407
The Siemens and Halske Safety-Clutch. E. Richter 408
Apparatus for Telephone-Exchanges. G. de la Touanne 408
The System of Electric-wiring of the Interior-Conduit and Insulation Company. E. H. Johnson 410
The Ducretet Signal Switch-board. H. Mamy 412
The Electric Cables through the Gotthard Tunnel. — von Baechtold . 413
The Central Electric-Light Station at Hannover. W. Kohlrausch . . 413
The Municipal Electric-Lighting Station at Paris. F. Meyer 414
The Electric Lighting of Railway Trains. F. Uppenborn 416
The Repair of Glow-Lamps. J. A. Montpellier 417
Power-Transmission by Alternating-Currents. M. von Dolivo-Dobrowolsky 417
Electric Transmission of Power by Alternating-Currents 419
The Applications of Gutta-Percha. — Lagarde 420
High-Speed Electric-Railway Work. O. T. Crosby 421
Cable- and Electric-Railways. H. M. Kebby 422

Digitized by Google

PAGE

The Budapest Electric Tramways. F. UPPENBORN 424
A Photographic Study of the Electric Arc based upon Experiments made by Mr. J. C. McMynn. Prof. E. L. NICHOLS 425
Giraud's Thermo-Electric Stove. E. HOSPITALIER 426
Some possible Modifications in the Methods of Protecting Buildings from Lightning. N. C. D. HODGES 427
Note on an Underground Line laid in a Cement Conduit. E. BRYLINSKI . 427
On the Determination of the Dielectric Constant of Glass for very Rapid Oscillations. R. BLONDLOT 428
The Soldering of Glass and Porcelain Tubes to Metals. — CAILLETET . 428
Cailletet's Cryogene. MAX DE NANSOUTY 429
The Schiseophone. E. FLACHAT 430
A Baroscopic Thermometer 431
The Pressure-Gauge on the Eiffel Tower. MAX DE NANSOUTY 432
The Influence of Lightness upon the Cost of Construction of Vessels . . 434
The Causes of the Vibrations of Screw-Steamers. D. W. TAYLOR . . . 435

INDEX. 437

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1890-91.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

3 March, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

JOHN POICTEVIN LEMON HOGAN. | THOMAS DE COURCY MEADE.

The following Candidates have been admitted as

Students.

GEORGE ROBERT BALE.
EDWARD CECIL BARTLETT.
JOHN BOYD BRODIE.
IGNATIUS BULFIN.
DAVID CARNEGIE.
WILLIAM ROBERTSON COPLAND, Jun.
CHARLES CRIGHTON.
GORDON DOUGLAS.
RICHARD CRAIG FARRELL.
WILLIAM ROBERTSON LIDDERDALE FORREST.
ARTHUR LIVESEY FORRESTER.
JOHN WISHART FAIRLIE GARDNER.
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THOMAS HART.
FREDERICK GEORGE HEATON.
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LEONARD LIONEL JOSEPH.
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LIONEL TRUNINGER.
ARCHER TURNER.
GEORGE UZZIAH WHEELER, Wh.Sc.
PERCY FREDERIC WICKHAM.
GERARD BOURCHIER SHERARD WREY.

The following Candidates were balloted for and duly elected as

Members.

CHARLES EDWARD BAINBRIDGE.
HENRY WILLIAM VAUGHAN COLEBROOK.
JAMES ALFRED EWING, B.Sc., F.R.S.
FRANCIS CLARKE GAMBLE.
WILLIAM EDWARD GARFORTH.
HENRY ALFRED GRAY.
ROBERT LEWIS HARRIS.
ALFRED EPHER HUNT.
WILLIAM PIERSON JUDSON.
JOSEPH LINDLEY.
FREDERICK CHARLES MURRAY.
ALFRED GEORGE WOODWARD REID, C.M.G.
WILLIAM HUGH WOODCOCK.

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KRISHNACHANDRA BANDYOPADHYAY.
REGINALD BELFIELD.
ARTHUR HOWARD BENHAM, Stud. Inst. C.E.
MICHAEL GRAHAM BERKLEY.
WALTER BOND.
FREDERICK WILLIAM CARNE, Stud. Inst. C.E.
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HENRY GEORGE COLE, A.K.C.
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ALFRED DRYLAND, Stud. Inst. C.E.
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WILLIAM HENRY LEETE.
ROBERT FLETCHER LESLIE.
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JOHN STUART ELLIS DE VESIAN, Stud. Inst. C.E.
ALEXANDER WILSON.

An Associate.

ALEXANDER NELSON RADCLIFFE.

(*Paper No. 2507.*)

"On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London."

By JOHN THORNHILL HARRISON, M. Inst. C.E.

"THE subterranean water in the valley of the Thames and its relation to the supply of London," which is included in the List of Subjects issued by the Council of the Institution, affords a wide field of inquiry, and one which could hardly with advantage be considered in a single Paper. It has therefore been decided to confine the present observations to the subterranean water in the chalk formation of the Upper Thames, and its relation to the supply of London.

Questions more or less connected with this subject have, on several occasions during the last fifty years, been brought before the Institution, and they have elicited excellent discussions.

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Several projects also for the supply of London from the chalk have been suggested, of which two at least have failed to obtain Parliamentary sanction for their execution. One of these was the scheme propounded by Mr. Robert Stephenson in 1840 for the supply to the north-west of London of 10,000,000 gallons of water daily from a well at Bushey Meads, near Watford. This project was opposed by the mill-owners in the neighbourhood, who contended that "this quantity of water must be obtained from the same source whence the springs which fed the mill-streams was derived, and that whatever quantity of water was pumped from Bushey Meadows, the same amount would be abstracted from the mill-streams, the pressure being relieved which caused the overflow of the springs." [1] Under the other scheme, promoted by the Grand Junction Waterworks Company in 1888, it was proposed to obtain 20,000,000 gallons of water daily for London from the Thames and from adjoining gravel-beds at Dorney, situated a few miles above Windsor. This, also, was defeated on the second reading in the House of Commons, without any inquiry into the merits of the scheme. Each of these plans was rejected for the same reason, viz., the fear that the volume of water in the rivers Colne and Thames, respectively, would be largely diminished, to the serious injury of persons interested in those rivers.

The Royal Commission on Water-supply, 1866, took a similar view of the subject, and reported thus—

"We do not agree with those who expect to get an almost unlimited increase of quantity of water by simply tapping the natural reservoirs in the chalk, for the supply to them must obviously be limited by the amount of rainfall. Moreover, as the water which penetrates into the reservoirs, raising the water-line more or less above the level of the adjoining valleys, ultimately in greater part finds its way by springs into streams at the lower level of the district, any water drawn from the store by artificial means will most probably be at the expense of those streams; if this be true, it follows that any water obtained by tapping the chalk reservoirs that feed either the river Lea or the Thames above Hampton, would only, *pro tanto*, diminish these streams, and would therefore be little or nothing gained to the general supply."

The strong feeling and the fears entertained by persons interested in these views are well described in the following passage from Dr. Evans' anniversary address in 1876,[2] as President of the Geological Society:—

"It will, I think, come within the province of the geologist to point out not only where spring-water of good quality is to be obtained, but also what will be

[1] Minutes of Proceedings Inst. C.E., vol. xiv. p. 47.

[2] Quarterly Journal of the Geological Society, May 1876, p. 116.

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the effect of its abstraction upon the districts where it now exists in sufficient abundance to overflow into the streams. It will be for him to show what will be the effect of producing a 'void below the level at which the drainage of the country naturally escapes;' how what are now fertile and even irrigated meadows will be converted into arid wastes; how water-cress beds, now of fabulous value, will be brought to the resemblance of newly-mended turnpike roads; how in such a district all existing wells, many of them already some hundreds of feet in depth, will be dried, the mill-streams disappear, and even the canals and navigable rivers become liable to sink and be lost in their beds. And these results would, if the scheme were carried out, not be confined to some single spot, but would extend over hundreds of square miles."

It is evident, from the context, that Dr. Evans here refers to the abstraction of water from the chalk-formation, and a suggestion to supply London in this way in 1884 was thus noticed by him in his lecture on "Physiography" delivered at this Institution in 1885 [1]:—

"Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished by just the same amount of water as that abstracted by means of the tunnels."

It cannot be doubted that apprehensions of this kind, unless they are removed or proved to be groundless, will always be sufficient to cause the overthrow in Parliament of any proposal to supply London with water from the chalk formation. It would, consequently, be a useless waste of time to submit a Paper on this subject to the Institution unless the Author of it were prepared to give, as he believes, convincing proofs that no such disastrous consequences would result from the proposal.

It becomes necessary, then, to show, not only that the Upper Thames chalk-basin can afford the water-supply required, abundant in quantity and excellent in quality, but also that a sufficient quantity of water can safely be withdrawn from the chalk formation without detriment to the Thames or to any of its tributaries.

Quantity of Water.

The question of quantity is the more immediate subject of this Paper, and in order to be able thoroughly to grasp it, attention may be directed, in the first place, to some peculiarities of

[1] "The Theory and Practice of Hydro-Mechanics," p. 18. A Series of Lectures. Session 1884–85.

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the chalk formation which were laid before the Institution by the late Professor Ansted in 1850,[1] as the result of careful experiments. He distinguished between the upper, or flint-bearing chalk, and the lower chalk or clunch, which latter is darker in colour, and is often affected by the presence of particles of silicate of iron, whilst in texture it is apparently rather closer and harder than the upper chalk. A cubic foot of the Upper Chalk weighs nearly 159 lbs., and of the Lower Chalk barely 154 lbs. In round figures the chalk, when saturated, will hold on an average 2 gallons of water in a cubic foot, or four times as much as the New Red Sandstone. One square mile of dry Upper Chalk, 1 yard in thickness, always contains nearly 3,500,000 gallons of water, and when saturated 200,000,000 gallons; whilst in the same area and depth of the Lower Chalk there are when dry 12,000,000 gallons, and when saturated 180,000,000 gallons of water.

The much larger quantity of water which the Lower Chalk holds when dry is due to its greater capillary attraction; this power, together with the avidity with which it clings to the water contained in it, is of great importance, as in consequence of its upheaval the Lower Chalk forms the lofty ridges encircling the Thames basin, and upholds the surface of saturation at a much higher level than the Upper Chalk could have done.

This phenomenon is remarkably illustrated in the chalk-basin from which the River Wandle derives its supply. In a well at Banstead, which is situated on the apex of a semi-conical area of chalk, the water stands 260 feet above Ordnance datum, and its level does not vary more than 5 feet between the driest and the wettest seasons; whilst at Carshalton, which is only 3 miles from Banstead, the water issues from the springs at 120 feet above Ordnance datum, or 140 feet below the water in the Banstead well, the level being upheld in the latter place by the Lower Chalk.

The water in the chalk formation is ordinarily carried to the point of issue by means of fissures of greater or less width, into which it has gradually filtered from the compact chalk. Were it not for fissures it would be difficult to conceive how the water falling on the chalk in the neighbourhood of Devizes, could be carried to the Thames between Wallingford and Streatley, a distance of 40 miles, and from thence onwards to Maidenhead.

---

[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 360 *et seq.*

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Proportion of the Rainfall that sinks into the Chalk.

The question of the proportion of the rain which sinks into the chalk to that which is evaporated from the surface, or is absorbed by vegetation, has frequently been brought before the Institution. A debt of gratitude is due to such careful observers as Messrs. Lawes and Gilbert, Mr. Greaves, and Messrs. Dickinson and Evans, who have from time to time recorded the results of experiments conducted by them.

It is admitted that, in almost all cases, the whole of the rain which falls upon the chalk sinks immediately into the ground, and does not run off its surface; that rivers fed from chalk-springs alone are very rarely flooded; and that when the bournes run and largely increase the volume of a stream, they do so some weeks, or even months, after the heavy rainfall which has occasioned them.

The following passages from Dr. Evans's lecture on "Physiography," which give the results of Mr. Dickinson's and of Messrs. Lawes and Gilbert's experiments, may be regarded as the most reliable information which can be obtained on infiltration.

Dr. Evans says of Mr. Dickinson's experiments[1] that the average of thirty years shows that, out of a total rainfall of 27·843 inches, 10·65 inches passed through 3 feet of chalk. Of this quantity 2·118 inches percolated during the summer months, when vegetation was in progress and evaporation was greater, and 8·532 inches percolated during the winter months.

He also says that Sir J. B. Lawes' and Dr. Gilbert's gauges

"were constructed of round blocks of the natural soil, with a surface area of $\frac{1}{1000}$ part of an acre, and a depth of 20, 40 and 60 inches respectively. The surface of these plots was kept free from vegetation by being occasionally hoed, and the following were the results for the ten years, 1871 to 1880. Out of a mean rainfall of 31·451 inches, 14·04 passed through 20 inches of soil, and 13·241 through 60 inches; or, dividing the years into summer and winter periods of April to September and October to March, it appears that out of 16·365 inches of summer rain only 4·111 found its way through 60 inches of soil, while in the winter there passed 9·13 inches out of a rainfall of 15·086 inches."[2]

These experiments were made in the neighbourhood of London where the average rainfall is given as 27·843 and 31·451 inches respectively; but the average during fifteen years, from 1866 to 1884 at Marlborough, amounted to 33·97 inches, whilst

[1] "The Theory and Practice of Hydro-Mechanics," p. 17. A Series of Lectures Session 1884–85.

[2] *Ibid.*, p. 16.

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during the same period in London it was only 26·14 inches. The percolation over the lofty downs in the west would much exceed that given by these experiments, not only on account of this large excess of rainfall, but also on account of the probably much smaller quantity evaporated from the surface of the land. The evaporation from the surface of water on the downs is so much exceeded by the condensation, that the dew-ponds, which owe their existence to this excess, afford a sufficient supply for large flocks of sheep in places where no other water can be obtained except from great depths below the surface.

It is desirable that the accuracy of the foregoing results should, if possible, be tested, and this could best be done by obtaining a careful record, extending over a sufficiently long period, of the quantity of water yielded by the springs issuing from a well-defined gathering-ground, and by comparing these results with the rainfall on that area through a number of years. It would be necessary, of course, to measure all the springs in order to obtain a correct result. It would not suffice, for instance, in the case of the chalk-basin of the upper Thames, to gauge the quantity of water discharged by the Kennet, the Wye, the Colne, and that collected by the Thames between Wallingford and Maidenhead, because the chalk formation is tapped between Maidenhead and Datchet at a decidedly lower level, and thus discharges a quantity of water which it is hardly possible to estimate.

The River Wandle, however, is very differently situated, as the chalk which supplies it is not tapped anywhere in this manner; and if long-continued gaugings of that river at Hackbridge, where all the streams from the springs unite, were available, they would afford the information which is required.

It is most probable that there is no water communication between the chalk of the Wandle gathering-ground, and that which extends from Devizes to Hertford, as the abrupt alteration in the dip of the strata between Epsom and the Hog's Back suggests the probability of a north and south disturbance on the west side; whilst the great east and west disturbance through London, and the north and south disturbance on the east side of it (which will be presently described), effectually bar the passage of water in those directions.

Long-continued gaugings of this character are not to be had, but information on this subject is not altogether wanting, and it is desirable that the results to be deduced from it should be ascertained.

First, as to the extent of the gathering-ground, which is fairly well defined by the north and south fault on the east of London, by the limits of the Chalk on the south, by its outcrop from

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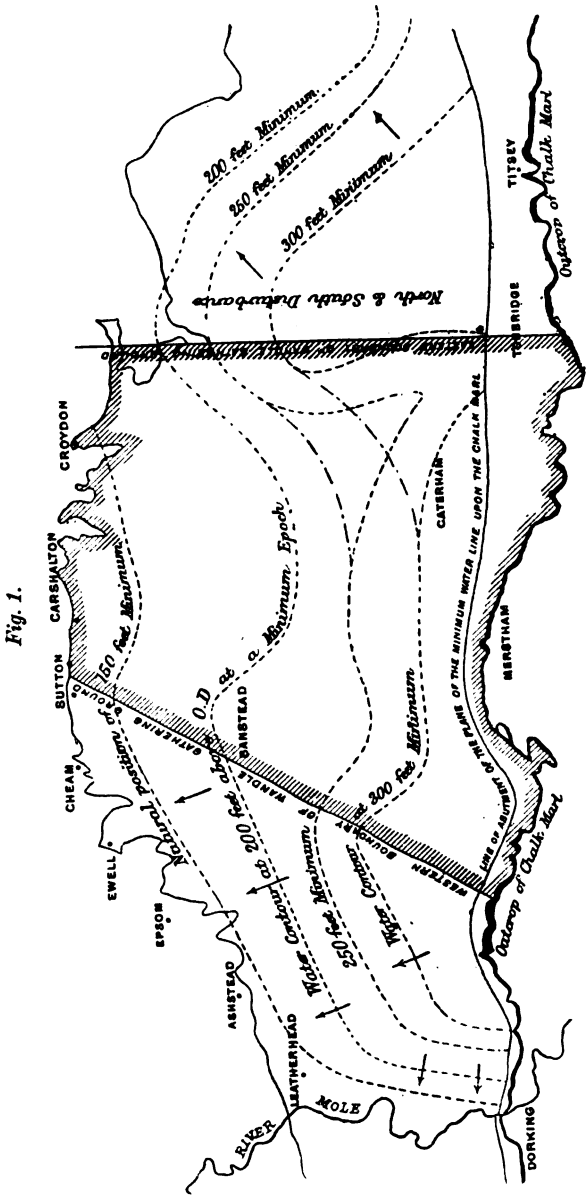

THE CHALK GATHERING-GROUND OF THE RIVER WANDLE.

under the tertiary beds on the north, and by a line approximately definable on the west. This area, corresponding as it does with the drainage area above Hackbridge, may be assumed to be 56 square miles, as given by Mr. Homersham [1] from actual measurement.

Some of the water which falls on the Wandle area is no doubt pumped from wells sunk to the chalk on the south side of London; this quantity may be taken at from 3,000,000 to 4,000,000 gallons a day; the only natural outlets for the water of this district are the springs which feed the Wandle at Carshalton, Waddon and Croydon.

Mr. Braithwaite, in his Paper "On the Rise and Fall of the River Wandle," [2] gives the following summary of all the gaugings of the Wandle at the union of the streams above Hackbridge, taken early in the spring of the year 1853:—

First average	63,488,520 gallons per day.
Second average	52,750,980 „ „

As Mr. Homersham pointed out in the discussion on that Paper, the former volume would be equal to nearly 29 inches of rainfall per annum, while the latter would give 23½ inches. It is evident that these gaugings do not afford a solution of the problem, and Mr. Braithwaite gave the following explanation:—

"These quantities (the gaugings of the River Wandle) refer to a period when the river, its bed and the adjacent soil, had been saturated with heavy rains; they consequently afford no criterion of the quantities during dry seasons."

But, he added:—

"It may be concluded that in a season of drought the true source of supply to the Wandle is to be found at Waddon and Carshalton only, for the bourne becomes dry and the Croydon springs are polluted. At present (1853) the supply from Waddon and Carshalton is found to amount to 32,941,800 gallons daily, but when the land springs and other drainage waters are exhausted, there are only 18,367,920 gallons daily available for water supply, supposing the flow from the chalk to continue uniform."

The Croydon springs must not, in consequence of their pollution, be excluded in considering the question of the total quantity of water discharged, nor should the bourne be omitted because it becomes dry. Taking the above data and allowing for the water pumped from the chalk, the average daily discharges from the chalk gathering-ground of the Wandle may safely be estimated to be at least 30,000,000 gallons, which is equal to 13½ inches of rain falling annually on 56 square miles. This depth is considerably

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 217.
[2] *Ibid.*, vol. xx. p. 197.

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in excess of the result of Mr. Dickinson's experiments extending over thirty years, as given above, viz., 10·65 inches; but it accords fairly well with the experiments of Messrs. Lawes and Gilbert, and it is not so large as that given by Professor Ansted, who said [1]:—

"The mean annual rainfall in the east of England may be estimated at 26 inches, of which at least 18 inches cannot fail to be received into the mass of the rock."

It now remains to estimate from these data the quantity of water which is probably absorbed by the chalk formation of the upper Thames to the west of London, exclusive of that falling on the gathering-ground of the Wandle, Beverley brook and the Hog's Mill river.

Reference to Map.

The accompanying map (Plate 1) shows the chalk-basin westward of London, and includes the entire area referred to in this Paper; it will be observed that this area has the outline of a horse-shoe, formed by the upheaval of the Chalk, and that the Upper Greensand, which is exposed in an almost continuous line beyond the chalk, defines, with great precision, the limits of the basin; the Lower Chalk is raised generally to the highest level, and occupies the high lands round three sides of it, and is thus in the most favourable position for upholding the water in the saturated chalk to the highest possible level.

The London Clay overlies the Chalk to a considerable extent in the lower and eastern portions of the horse-shoe basin, and prevents (except where it is artificially tapped by boring) any water from escaping towards the sea, except such as may pass over and on to it at certain points where the Chalk crops out at a low level from beneath the Clay. These points are few in number, and are approximately the following: the springs which feed the River Wandle, the lowest of which is 120 feet above Ordnance datum; the springs at Sutton, Cheam and Ewell which feed the Beverley brook and the Hog's Mill river, and which issue at nearly the same level; and the rivers Mole and Wey, which cross the chalk ridge rising along the Hog's Back to 500 feet above Ordnance datum, by gorges at 129 and 109 feet respectively above Ordnance datum. These latter rivers carry the water collected over very

[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 367.

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extensive areas of Greensand and Gault, and, in their passage to the Thames, cross the gravel-beds in channels rendered watertight by the muddy deposit brought from those formations and from the tertiary strata; the quantity of chalk-water flowing down in these two rivers is probably insignificant. The Loddon carries a small amount, chiefly derived from springs at Basingstoke and Old Basing. The Brent does not collect any water from the Chalk and becomes almost dry during the summer months.

The rivers, however, which are more immediately important are those which draw water from the large expanse of Chalk between Devizes and Hertford—an area of about 90 miles long, and from 13 to 18 miles wide, and which contains 1,200 square miles. These rivers are the Kennet, chiefly a chalk river, the Thames between Wallingford and Maidenhead, and the Wye, purely a chalk river, which joins the Thames near Maidenhead; these three having become united, cross the London Clay barrier at Datchet at a level of 47 feet above Ordnance datum. The Colne and the Lea cross the tertiary formation about 120 feet above Ordnance datum.

The first point to be determined is how much water these three rivers, the Thames at Maidenhead (including the chalk-water contributed by the Kennet and the Wye), the Colne and the Lea draw annually from the chalk formation. No data can be obtained for a very accurate estimate of the volume, but approximately the average daily discharge is:—

From the Thames, Kennet and Wye . . .	150,000,000 gallons.
„ Colne and Lea	100,000,000 „
Total. . .	250,000,000 „

This quantity, if gathered over 1,200 square miles, would be equal to about 5 inches of rainfall per annum. But, according to Mr. Dickinson's experiments, the volume of water which sinks annually into the Chalk (and which must come out somewhere) is 10·65 inches. There remains, then, on the strength of his experiments, 5⅔ inches of rainfall which sink annually into this large chalk area, or, according to Messrs. Lawes and Gilbert's experiments, and the above estimate based on the flow of the Wandle, 8 inches of the rainfall, which is not discharged by the ordinary channels, and the problem is to determine what becomes of this water?

As bearing upon this subject, the following extract from Mr.

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Homersham's Report to the directors of the London (Watford) Spring Water Company [1] is instructive:—

"The area of land above, or sloping towards Watford, and consisting for the most part of steep chalk hills, embraces more than 1,200 square miles, and calculating that only a depth of 20 inches of rain per annum falls in this locality, at least one-half or 10 inches, may be considered as reaching the lower fissures; and that this last amount is underrated there can be no doubt, when it is remembered that here the yields of the rivers and springs only account for a small consumption of the depth of rain falling, and that the rapidity with which water is absorbed by the chalk formation prevents any large amount being carried off by evaporation. This depth of 10 inches of rain per annum, percolating through a surface of 1,200 miles, is equal to supply the immense quantity of 408,000,000 gallons per day, for every day in the year, which at present finds a vent and is discharged along the coast."

Mr. Homersham probably meant that the surplus over the small consumption "accounted for by the rivers and springs" was thus discharged along the coast.

Without insisting upon the extreme accuracy of the above figures, they are sufficiently correct to show that there is a large quantity of water, amounting to several hundred million gallons per day, falling upon and annually passing through this chalk area, which is not accounted for by the combined discharge of the Thames at Maidenhead, the Colne and the Lea.

It may be contended, as suggested by Mr. Homersham, that this large quantity of water escapes to the sea, but this is impossible, as its progress seaward is effectually barred by a disturbance or fault which runs north and south across the basin below London (as already mentioned); this fault and the eastward disturbance have been described by Professor Prestwich[2]; while the extension southwards, and the character of the north and south disturbance, are confirmed by Mr. Lucas, who says[3]:—

"At Tandridge Hill there was a large fault with the downthrow on the west, and another with the downthrow on the east, west of Titsey Park."

The direction of the two disturbances and the position of Tandridge Hill and Titsey Park are shown approximately by the black lines on the map.

There is probably another fault in a direction more or less from north to south, to the westward of Kensington, as indicated by the level of the chalk-water in artesian wells, which rises 30 or 40 feet above Ordnance datum at Chiswick, Hammersmith,

[1] Minutes of Proceedings Inst. C.E., vol. xiv. pp. 48–49.
[2] Prestwich on the Water-bearing Strata of London, p. 40.
[3] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 113.

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and Fulham, whilst in wells at Kensington and eastwards of it the water stands at 40 feet below Ordnance datum.

Now, as Professor Prestwich says the north and south disturbance cuts off the supply of water from Kent and Essex to London, so it must, in like manner, form an effectual barrier to the escape of water from the upper Thames chalk-area to the sea, as suggested by Mr. Homersham.

Where does the Water Escape?

The question then arises, where does the surplus water escape if its egress to the sea is barred? Before proceeding further to consider this question, attention must be directed to the annexed table of gaugings of the Thames. (See Appendix.)

The lowest level above the barriers at which the surplus chalk-water can possibly escape seawards over the surface of the London Clay is at Datchet, near Windsor, where that clay is about 47 feet above Ordnance datum, being there covered with gravel 12 feet thick and about 1 mile in width. This gravel-bed extends from Datchet westward to Maidenhead, and overlies the Lower Tertiary beds and the Chalk; in some parts it is 30 feet thick; it is hemmed in on the south and on the north by the London Clay, which rises to more than 40 feet above the valley between Salt Hill and Langley. This large extent of gravel is as essentially a reservoir as any lake in England; the difference being that it is only during excessive floods that the water rises above its surface. The water in the gravel near Dorney rises gradually from the level of the river northwards, and rarely, if ever, falls below it. This gravel reservoir is not supplied from the Thames, for, in that case, it would be found that the volume of the water decreased in passing down the river; but on the contrary, it has been ascertained that it increases. The increment thus supplied to the Thames between Maidenhead and Windsor was shown, by careful gaugings, to be:—

In April, 1884	. . . . .	137,000,000	gallons per day.
On July 8	„	36,000,000	„ „
„ „ 10	„	43,000,000	„ „
„ „ 22	„	17,000,000	„ „

It will easily be understood that the quantity which enters the river in this way may vary largely, day by day, in consequence of the level at which the water is maintained between the locks. Thus, when it is desired to pass onwards an excessive

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volume of water, the head at the weir would be kept down, in order to increase the velocity of the stream. The effect of this might be to considerably augment the influx of water into the river from the reservoir. Again, when the volume of water passing down the river is small, a high level at the weirs would be maintained in order to keep the reaches full, and thus the difference in level might be reduced to such an extent as greatly to decrease the quantity of water passing into the river. It requires some such operation as this to account for the great reduction in the increment shown to have taken place between the 10th and 22nd of July—seeing that it is most improbable that the water-level in the reservoir could have been sufficiently altered in that interval to account for all that difference. It must be remembered that the floods in the river occur with great rapidity, whereas the water in the reservoir, which, it is contended comes from the chalk formation, must rise very gradually, and may not be affected after heavy rains until some time after the river-flood has passed away.

This leads to the inference that the great floods in the Thames, from Windsor downwards, occur when the rains are not only very heavy, but also are so continuous that the ordinary river-flood and the chalk-bournes are both supplying their quota at the same time.

Gravel-bed and Underground River below Datchet.

The Author has now to consider what becomes of the water which must flow at Datchet on to the surface of the London Clay, which there forms an unalterable weir. The gravel-bed above Datchet, acting as a reservoir, to which allusion has already been made, extends eastward below Datchet, varying in depth from 12 to 30 feet; it is bounded by the London Clay and Bagshot sands on the south, and probably on the north by an extension of the London Clay barrier between Salt Hill and Langley (before mentioned). From thence it passes to the northward of the Grand Junction Waterworks at Hampton, where the London Clay forms a distinct barrier between the gravel-beds, and onwards to Kingston. This gravel-bed contains an area of about 40 square miles; it forms at once a large gravel reservoir and an underground river, the most free and open part of which consists of a clean coarse pebble-bed, at the bottom of the gravel. It has been found that the surface of the water in

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this gravel-bed rises, in some cases, with an inclination of about 8 feet in the mile from the Thames, the volume of which it increases at certain points; this increase occurs apparently chiefly where the Thames crosses the direction of the flow of the underground river. Thus it was found in April, 1884, that there was hardly any increment in the volume of the Thames between Windsor and Staines, but that between Windsor and Thames Ditton (exclusive of the volume contributed by the Colne, the Wey, and the Mole) there was a large increase. Thus:—

In April, 1884, the increase was			112,500,000	gallons	per day.
On July 8, 1884	„	„	13,000,000	„	„
July 22 to 26	„	„	114,000,000	„	„

Here it is evident that there must have been some disturbing conditions at work in the river between the 8th of July and the week from the 22nd to the 26th of July. It is most improbable that the level of the water in the gravel-bed could have altered, in the interval, sufficiently to account for this great difference.

The total increase in volume in the Thames between Maidenhead and Thames Ditton was (exclusive of the Colne, the Wey, and the Mole)—

In April, 1884	249,500,000	gallons	per day.
On July 8, 1884	49,000,000	„	„
July 22 to 26	131,000,000	„	„
And Nov. 1890	45,000,000	„	„

A portion of this increment passes into the gravel-bed from the Bagshot-sand formation, and, when this quantity forms a considerable proportion of the entire volume of the Thames at Molesey, it gives to the water now supplied to London a decidedly chalybeate taste.

The Author has suggested that the underground river in the Windsor gravel-bed is abruptly terminated by the meeting of the London Clay barriers at Kingston, and it might reasonably be expected that there would exist some evidence of such a condition of things. Such evidence seems to have been afforded by the existence of the "Seething Wells" at Kingston and Thames Ditton. There are no means of ascertaining the volume of water which issued from these wells, but it must have been carried through the gravel under considerable pressure to have produced the Seething Wells which would not have been formed if there had been free means of egress for the water to the river below Kingston.

The London water companies have for many years past pumped a large quantity of water from this gravel-bed.

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Slough Gravel-Reservoir and Underground River.

Attention must next be directed to a large gravel-bed, which lies to the north of the barrier between Slough and Kingston. This gravel-bed extends over a large tract between Burnham on the west and the eastern part of London, and covers an area of about 50 square miles. It forms between Slough and Brentford an extensive reservoir and an underground river by which a large volume of water is carried to the Thames.

This gravel-bed is crossed by the Thames nearly at right angles between Kingston and Brentford, where it is, for the greater part of the distance, an open tidal river, and being unaffected by locks, the water can flow freely into it at all times, excepting when the tide is up. The late Mr. Beardmore, in his evidence before the Royal Commission on Water Supply, 1866, said that "the Thames was supplemented to the extent of some 60,000,000 to 80,000,000" gallons of water "between Kingston and Vauxhall Bridge." It is not very clear whether he referred to the supply from the River Wandle, or to an imperceptible increment from springs in the bed of the Thames. In order to ascertain what volume of water entered this part of the river from the gravel, the Author had gaugings taken of the Thames at Teddington and at Kew in August, 1887, after a remarkably dry summer, and again in November, 1890, when the water-level in the chalk formation was abnormally low, with the following results:—

	Gallons.
The increment between Teddington and Kew in Aug. 1887 was	430,000,000
" " " " Nov. 1890 "	440,000,000

This large quantity of water must have entered from the gravel-bed. Some deductions should possibly be made on account of tidal interference with the flow from the gravel, though the quantity thus arrested is probably very small. Even granting, however, that several million gallons were thus diverted, there would remain an abundance of water, which might be withdrawn from this underground source, for the supply of London and its suburbs for centuries to come. This could be done without in any way interfering with the volume of water which is collected and carried by the Thames between Maidenhead and Teddington, while the withdrawal of 100,000,000 gallons of water daily from the Thames at Hampton by the Water Companies might be discontinued.

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WHAT IS THE SOURCE OF THE SUPPLY OF THESE TWO RESERVOIRS?

The Author has now to deal with the question, whence does the water come which is carried by these two underground rivers, from Windsor and Slough?

There can be no hesitation in replying that it must come chiefly from the chalk formation; the supply of the Windsor gravel-bed being drawn from the Chalk which lies to the westward of a line passing from somewhere near Dorney directly northward to the boundary of the chalk basin, and that of the Slough gravel-bed from the Chalk which lies to the eastward of that line. This latter area corresponds substantially with the gathering-grounds of the rivers Colne and Lea.

The area of the Windsor gathering-ground is		630	square miles.
,, ,, Slough ,, ,,		570	,, ,,
Total . .		1,200	,, ,,

The Kennet, the Wye, and the Thames collect in their channels, and carry down a large volume of chalk-water to the former area; whilst the Colne and the Lea alone collect water at a high level from the latter area, and carry it by their open channels to the Thames.

The water found in the Windsor gravel-bed has doubtless never been exposed to the light since it fell as rain on the far-distant hills to the west and north; and it is very probable that it is conveyed by a large fissure or fissures, which run westward in continuation of the great east and west disturbance, marked on the map by the black line between Deptford and Maidenhead, and along the synclinal axis of the chalk basin. It might reasonably be expected that a large volume of water would be found issuing at the lowest point of discharge on this line, in the same manner as the numerous and powerful springs issue near Havant, a little above the sea-level, and discharge, it is estimated, about 200 million gallons a day from the synclinal axis of the Hampshire chalk basin.[1]

That large fissures exist in the Thames basin is proved by the occurrence of one in the long chalk-cutting on the Great Western Railway between Maidenhead and Twyford, into which the surface drainage of the cutting was drawn off for many years.

[1] Mr. Ewens' Evidence before Royal Commission on Water-supply, 1866. Question 3767.

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An excessive and continuous rainfall then occurred, when this fissure became, instead of a drain, a powerful bourne, which flooded the line to such an extent that it became necessary to construct large culverts to carry off the water to the ends of the cutting.

It is unnecessary to say more respecting the source of the supply than that the water in the Chalk about Marlborough was standing at Christmas, 1890, at a lower level than has been known for many years. The bourne which rises at times after heavy rains, at a point a little south of Chiselden village, at 505 feet above Ordnance datum, was then dry, or nearly so, for 5 miles down, and the water reaches the surface at 417 feet above Ordnance datum, at a distance of 1 mile from the junction of this bourne with the Kennet at Marlborough. Dr. Evans mentions a very similar case as occurring on the Colne area; he says:—[1]

"I have known the source of the little river Ver to be at least 5 miles further up the valley in one year than in another; and I have known the depth of water in a well, at a considerable distance from a stream, to vary as much as 70 feet in two consecutive years."

The Author is indebted to Mr. Trepplin and Mr. Shopland for the following figures, which show the great height at which, even after a long period of dry weather, the water now stands in the western chalk-reservoir, above the lowest outlet on to the London Clay at Datchet, situated, as already stated, 47 feet above Ordnance datum:—

The springs at Chiselden, 3 miles S.E. of Swindon	460	feet	above O. D.
In a well at Ogbourne Station	434	,,	,,
,, ,, Down Barn, North Donton Farm, 3½ miles west of Marlborough	441	,,	,,
In a well at Barbury Castle Farm, 4 miles S. of Wroughton	501	,,	,,
And in August, 1890, in a well at Hackpen Farm, S.E. of Wroughton	485	,,	,,

No large fissures can be shown to exist to account for the collection and discharge of the water which enters the Slough gravel-bed. The water from the Windsor reservoir passes over the lip of the London Clay, which forms presumably a nearly level weir, at Datchet; whereas the water entering the Slough gravel-bed passes over an inclined stratum of the London Clay which runs from Salt Hill to Stoke Court, in a line nearly due north and south, about 2½ miles in length, with a gradual rise from 100 feet to 200 feet above

[1] "The Theory and Practice of Hydro-Mechanics," p. 13. A Series of Lectures. Session 1884–85.

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Ordnance datum. To the westward beyond this line, and to the northward and north-eastward of it, the lower tertiaries cover the chalk over an extensive area like a damp sheet, and continue eastward between the chalk and the overlying London Clay.

Near to the western limit of the Tertiary beds and of the London Clay, there are numerous large ponds and ornamental lakes in the overlying gravel, in which the water is maintained at a very uniform level, but at very different heights above Ordnance datum. For instance, at the western limit of the Lower Tertiaries, Burnham mill-pond and the ponds on East Burnham Common, which are about 2 miles apart, stand respectively about 100 feet and from 200 feet to 240 feet above Ordnance datum. Again, towards the westward limit of the London Clay, the following sheets of water are at about the levels indicated :—

Baylis House Middle Green Parsonage Farm	Northward of Slough, stand from					Feet. 90	to	Feet. 100	above O. D.
Stoke Park Stoke Place Woxham Park Langley Park Iver Park	About 1 mile N. of Slough				„	110	„	130	„
Stoke Court Black Park	„	2 miles	„	„	„	160	„	170	„
Hedgeley Park Fulmer Place Denham Mount	„	3	„	„	„	190	„	200	„

The springs which supply these ponds and lakes furnish the water also to the gravel-bed and to the underground river, extending from between Salt Hill and Stoke Court on the west, to Twickenham, Isleworth, Brentford, and onwards between Wandsworth and Kensington to the east of London. In this case the Lower Tertiary Sands would appear to be the medium by which the water is collected from the Chalk.

Professor Prestwich, speaking of the water in the tertiary sand and in the Chalk beneath London, remarks :—[1]

"There appears also to be a strong probability that some communication, either natural or artificial, exists between these two waters. Some writers have considered that the chalk supplies water to deep sand-springs, whilst others, on the contrary, are of opinion that the sands supply the chalk."

It is suggested that, in this case, the water is collected from the Chalk and is carried by the Lower Tertiary beds to the inclined edge

[1] "Water-bearing Strata of London," p. 216.

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of the London Clay. The Chalk has probably numerous fissures through which the water passes and is carried to the sands beneath the surface, but there must be a large direct infiltration from the chalk into the sands, over the extensive area where they are in contact. A great quantity of water is also carried along rivulets on the surface of the Chalk to the Tertiary beds, which frequently rise above the level of the Chalk outcrop.

It is probable that the sands, which collect water from the Chalk, were deprived of much of the clayey material, which now forms the beds of brick earth overlying the gravel in the Thames Valley, during the glacial period, when the water, entering and passing through the Chalk and through these sands, was enormously larger in quantity and was subjected to a much heavier pressure than at present. In corroboration of this it is found that at Fulmer, which is situated about 2 miles north-east from Stoke Court, the gravel is 14½ feet thick, and the sands (Reading beds) 33¼ feet thick, together 47¾ feet of sand and gravel. Another well-section at the same place gives 52 feet of clay and sands (Reading beds).[1]

Now these tertiary sands do not transmit water through them very rapidly, and it is probably due to this cause that the supply to the gravel is so remarkably steady. A proof of this steadiness is found in the fact that in the well at Bushey, reported upon by Mr. Robert Stephenson in 1840, "the subterranean water stood at a normal level of 181 feet (above Ordnance datum), from which there was hardly any variation."[2]

Mr. Homersham, who, in the discussion on Mr. Lucas's Paper,[3] called attention to this fact, stated also that :—

"In the Chiltern Hills (which are about 15 miles to the north of Bushey Meadows), the normal maximum height he had known in the waterworks well, sunk through the chalk till it reached the gault clay, was 513 feet above Ordnance datum. This was after a series of wet years, and the lowest level after a series of dry years was 469 feet. . . . The fall of the water from the Chiltern Hills (to Bushey Meadows) at its maximum was 22 feet per mile, and at its minimum 19 feet per mile."

It will be observed that this minimum height of the water in the Chiltern Hills corresponds very closely with the present minimum height of the water in the Marlborough Hills as given above. The minimum height of the water in the Chiltern Hills is

[1] Whitaker's "Geology of London," vol. ii. p. 9.
[2] Minutes of Proceedings Inst. C.E., vol. ix. p. 370.
[3] *Ibid.*, vol. xlvii. p. 119.

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288 feet above the water-level at Bushey Meads, and 300 feet above the edge of London Clay at Stoke Court. These differences of level are remarkably large, when compared with those between the branches of the Colne and the water in the intervening hills, as given by Mr. Dickinson in the discussion on the "Absorbent Power of Chalk," in 1849.[1] The river rises 200 feet in 14 miles between Watford and Tring; this gives a uniform inclination of the water in the Chalk, on a line running nearly north and south, of 14 feet 4 inches per mile. But transversely, between the River Gade at Two Waters and the River Ver at St. Albans, a distance of 6 miles, the table-land rises 200 feet above those rivers, and the water in the Chalk between them rose only 20 or 30 feet—say 6 feet 8 inches to 10 feet per mile—when the water was at its maximum height, and this inclination was considerably reduced during a single summer. In this manner, then, the Colne and the Lea, with their numerous tributaries, are chiefly supplied with water from the intervening ranges, and they do not collect more than 5 inches of the rainfall.

When the steady withdrawal of water at the low level from the great mass of the chalk, over which the Colne and Lea with their tributaries only skim the surface, is compared with the quantity of water which those rivers collect from the chalk hills which rise between them, it is seen that the Colne and the Lea are taking their supply, only, as it were, from the skin of the chalk formation, whilst a much larger quantity of water is being drawn steadily but imperceptibly in some other way from the great body of the chalk below.

The quantity of water thus drawn off will probably never be capable of exact measurement, but if it be assumed that the average rainfall which passes into the Chalk is 13 inches—as appears to be the case over the Wandle watershed—and if allowance is made for 5 inches as the quantity carried off by the Colne and the Lea, a residue of 8 inches is left for the daily discharge above Slough. This gives, if distributed over 578 square miles, a volume of 226,000,000 gallons per day—a quantity much in excess of what will be required for London and its suburbs for a long time to come; and it may be remarked that the gaugings of the Thames between Teddington and Kew go far to prove that this quantity is very much within that which is actually so withdrawn.

[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 369.

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The System of Collection for London Supply.

There may possibly be a sufficient difference between the quality of the pure chalk-water, carried by fissures to the Windsor reservoir, and of that brought through the medium of the lower tertiary sands to the Slough reservoir, to make it desirable to prefer the one to the other for the supply of London. The better of the two supplies should be chosen, independent of other considerations.

If the Windsor reservoir water were to be preferred, the scheme for the collection and carriage of the water to Hampton suggested by the Author in 1884, might, with some modifications, be adopted. In this case, the water taken from the neighbourhood of Dorney for the London supply would have to be replaced, when required, by an equal quantity taken from the Slough reservoir and discharged into the Thames above Windsor.

There remains for consideration the means by which the water from the Slough gravel, if such should be preferred, should be collected and conveyed for the London supply. Three methods suggest themselves as practicable, in each of which the water would be brought to a service reservoir near the Grand Junction Waterworks at Hampton, and from this it could be distributed to the pumping-stations of the several companies, for transmission, without filtration, through the existing mains to London.

The cheapest and most easily executed method would be to construct a culvert in a northerly direction from the Hampton reservoir across the course of the underground river to Cranford, a length of about 6 miles, keeping it to the westward of Hounslow and Heston. This culvert should be laid upon the London Clay, so as to form a complete dam, but the upper part of it should be at such a level that the extra water could freely pass over it at a lower level than that at which the water at present stands in the gravel. The water would be admitted under control at the points where the largest underground streams were encountered; manholes with sluices, &c., being constructed at these points. This method is open to the serious objection that the water might be polluted by the heavy manuring on the lands to the westward, and that these lands, though now but sparsely populated, might hereafter be built upon.

Another method would be to construct a culvert from the Hampton reservoir to Salt Hill, and to convey the water to it by means of an open-jointed collecting culvert laid along the road from Salt Hill to Farnham Royal. A suggestion to obtain water

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for London in this manner was made by the Author in his reports to the Local Government Board in 1884, in which he said[1] :—

"From this level area" (between Datchet and Maidenhead), "the chalk, covered with a thin bed of the lower tertiaries and with gravel, rises towards Farnham Royal; there is no doubt but that on this sloping area, as well as from the level area below, a large volume of water rises into the gravel and passes eastward to the Thames."

And again, in a note on page 12 :—

"A drift in the chalk along the road to Farnham Royal would probably yield a large volume of soft water, filtered through the chalk from the overlying Reading beds."

The road from Salt Hill and Farnham Royal runs parallel to the edge of the London Clay, over which the water flows into the gravel towards London. This method would be quite free from objection on the score of possible pollution; but it might be opposed by the owners of the several ornamental waters, with the level and supply of water to which it might possibly interfere.

Another alternative scheme would be to collect the water in a similar manner by a culvert running north and south, westward of the Colne Valley, between Langley Marsh and Uxbridge, a length of about 4½ miles; this would be free from objection both on the score of pollution and of interference with the amenities of the influential owners of private property.

The Author feels that, owing to the want of a sufficient number of careful observations, continued over a long period, he has not been able to present the entire subject for consideration in so clearly demonstrable a form as he could have wished; but as regards the chief object of the Paper, which is to show that it is possible to obtain an abundant supply of excellent water for London from the chalk formation, without detriment to any existing interests, the proof is not far to seek.

It has been here stated that, according to gaugings, carefully taken for the Author by Mr. Martin Peirce, Assistant Engineer to the Corporation of Richmond, the increase in volume of the Thames, between Teddington and Kew in August 1887, after a remarkably dry summer, was 430 million gallons per day, and that in November 1890, when the water in the Chalk at Marlborough was lower than it has been known to be for many years, this increase in the volume of the Thames was 440 million gallons per day. The accuracy of these gaugings can readily be tested.

[1] See Returns to House of Commons on Water-Supply of Metropolis, 1st December, 1884, p. 11.

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This water must come from the gravel-bed which overlies the London Clay to the westward of Teddington, and which is known to contain a large quantity of water in motion. Following this gravel-bed westward, there is found, before it leaves the London Clay, a number of large ponds and lakes, which are constantly kept filled with an unfailing supply of water. The accuracy of these conditions can likewise be easily verified. Following the gravel-bed further, it is shown to overlie a large extent of Lower Tertiary beds, abounding in water and resting upon the Chalk, which has an extensive gathering-ground to the north and north-east from which the water must be derived. The correctness of this assumption may soon be determined.

The suggestion in the Paper as to the means by which the water is collected from the Chalk and conveyed to this saturated gravel-bed may be disputed; but no objection on that score can affect the fact of the presence of this water in the gravel.

The Paper is accompanied by the drawings from which Plates 1 and 2 and *Fig. 1* have been engraved.

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APPENDIX.

GAUGINGS OF THE THAMES, IN MILLIONS OF GALLONS.

—	Wallingford.	Maidenhead.	Increment.	—
1865	240	320	80	Exclusive of the Kennet and Loddon.
Nov. 1890.	180	246	66	

—	Maidenhead.	Hampton.	Increment.	—
April 1884	673	923	250	Exclusive of the Colne and the Wey.
July 8 „	417	466	49	
„ 10 „	373	504	131	
„ 22 „	336	532	196	Including the Tributaries.
„ 23 „	380	519	139	
„ 24 „	397	537	140	
„ 25 „	391	575	184	
„ 26 „	385	480	95	
Nov. 1890.	346	446	100	

—	Teddington.	Kew.	Increment.	—
August 10, 1887. . .	301	731	430	
„ 12, „	332	681	349	
Nov. 1890.	454	894	440	

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Discussion.

Sir John Coode. Sir JOHN COODE, President, asked the indulgence of the members while he referred to a personal matter. It was more than fifty years ago that he first met Mr. Harrison at the Paddington terminus, when they were both young men just out of their articles, and he had had the pleasure of his friendship ever since. It was therefore a peculiar satisfaction to him to be present on that occasion, to listen to his old friend's Paper. He need hardly say that the supply of water to the Metropolis was a matter of vital moment, especially at the present time. If any one entertained a doubt on the subject, he would refer him to a letter in *The Times* of that morning from Mr. Symons, whom he was glad to see present, and who, he hoped, would take part in the discussion. In illustration of the great importance of the water-supply to London, he might mention that the proportion of the population of the Metropolis to that of the United Kingdom was within measurable distance of one-eighth. He was quite sure that they would all unite in passing a cordial vote of thanks to Mr. Harrison for his Paper.

Mr. Harrison. Mr. J. T. HARRISON asked permission to explain the diagrams which he had, at the suggestion of the President, placed on the wall since the meeting at which the Paper was read. Fig. 1, Plate 2, was a section from Banstead to Carshalton, and by Streatham to Battersea and Chelsea. The water-level mentioned in the Paper as being 260 feet above Ordnance datum at Banstead, was marked on the section. The water issued from springs at Carshalton and Croydon between 110 and 130 feet above Ordnance datum, and flowed into the Wandle. At Streatham, the Chalk was 131 below, whilst the water stood at about 55 feet above Ordnance datum. In the neighbourhood of Tooting and Balham, the water rose in many places above the surface. Passing to Battersea and Chelsea there was a great change, the water being met with at 55 feet, and the Chalk at from 232 to 238 feet below Ordnance datum, whereas at Streatham it was 131 to 100 feet below it. There appeared, therefore, evidence of a fault or disturbance between these two points, which agreed with the east and west disturbance pointed out by Professor Prestwich.

Fig. 2, Plate 2, was a section taken on the other side of the valley of the Thames, from the Chiltern Hills to Bushey Meads, where the normal level of the water, in the famous well mentioned by Mr. Robert Stephenson about 1840, was said to be 180 feet

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above Ordnance datum; whereas, in the well on the Chiltern Hills, at a distance of 13 miles, it stood at a maximum of 513 feet, and a minimum of 468 feet above Ordnance datum; the maximum inclination being 22 feet in a mile, and the minimum 19 feet per mile. He had extended the section onwards through Harrow and Perivale to Brentford. It would be observed that there was a considerable elevation of London Clay at Bushey, which explained an observation he had made in the Paper as to the arrest of water passing from the Chalk by the London Clay. At Harrow water was found at 101 feet above Ordnance datum, and at Greenford, near Perivale (50 feet above Ordnance datum), it rose to the surface from a bore-hole into the Chalk, as it did also at Brentford. The Chalk dipped underground after Bushey was left, with the same inclination that it had above ground. Mr. Harrison.

Fig. 3, Plate 2, was taken in the same locality as Fig. 2, in one of the valleys that had been scooped out of the Chalk—a mere surface indentation, as it were—along which the River Gade flowed, according to observations made by Mr. Dickinson many years ago, with a regular fall of about 14½ feet per mile, or 200 feet in 14 miles, exactly similar to the adjoining railway. The cross-section extended from the "Two Waters" on the Gade, midway between Tring and Watford, to the River Ver at St. Albans; the table-land rose about 200 feet above these streams, and Mr. Dickinson found it was necessary to sink from 170 to 180 feet below the surface midway between them, in order to reach water.[1]

An important point mentioned by Mr. Dickinson was, that the

[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 370. Mr. Dickinson said:—"Between Watford and Tring, on the London and North-Western Railway, there was a rise of about 200 feet, and subterranean water was found all along the valley, at an equal distance below the surface of the rails, the water-line taking very nearly the same inclination as the railway."

Minutes of Proceedings Inst. C.E., vol. xiv. p. 72. Mr. S. C. Homersham said:—"On sinking a well at Tring, water was commonly found in the chalk, standing at a level of about 450 feet above Trinity high-water mark, from whence the water-level gradually declined, in a south-easterly direction, to the level of the sea, and could be traced, issuing in large volumes, at various places along the coast."

Minutes of Proceedings Inst. C.E., vol. ix. p. 370. Mr. Dickinson said:—"Water found in the cracks and fissures of the chalk, at a moderate depth from the surface, was always in a nearly level line, taken transversely to the dip of the stratum, which corresponded very closely to the level of the water in the nearest stream. In digging wells in the high table-land, about 6 miles in width, situated between the River Pade, at Two Waters, and the River Ver, at St. Albans, and which was about 200 feet above the level of the water in those rivers, it was necessary to sink to the depth of 170 feet, or 180 feet, before water was found."

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Mr. Harrison. water appeared to arrive at these two rivers by means of fissures in the Chalk, and that it stood very nearly at the same level in each; so that it percolated through the Chalk into the fissures, and was carried right and left across the dip of the stratification to the adjoining river.

Fig. 4, Plate 2, was a section taken from Stoke Common, nearly in a north and south line, through Windsor Castle. To the north of Slough the Chalk fell nearly with the same inclination as the surface, and was covered by the Lower Tertiary beds and the London Clay, with a quantity of gravel overlying both. There was a rise in the Chalk at Slough which, together with that of the clays to the southward, separated the water that came into the Slough gravel from that in the lower gravel in the Thames basin proper between Dorney and Windsor. Fig. 4 showed approximately the valley of the Thames between Slough and Windsor Castle, where the gravel was beautifully clean and full of water. Windsor Castle was marked on Professor Prestwich's map as being nearly over the line of the great east and west disturbance. At a short distance to the south of Windsor the Chalk was 300 feet below Ordnance datum, and it continued to dip for some distance, after which it rose, and cropped out again in the line of the Hog's Back, where it lay at a very steep angle; the intervening hollow space being filled with Lower Tertiary beds, the London Clay, and the superimposed Bagshot sands.

Fig. 5, Plate 2, was a section running east and west from Staines to Dorney, along the centre of what he had called the Windsor gravel-bed. Above Datchet, towards Maidenhead, there was a great depth of gravel, with the Chalk, the Lower Tertiary beds, and in some parts the London Clay, lying below it. This gravel was full of water derived from the Chalk and the Lower Tertiary beds. At Datchet, the London Clay cropped up, and the water was thrown in the gravel above it, and passed onwards until it entered the Thames, chiefly between the Colne and Hampton, where the river ran nearly at right angles to the course of the underground water.

Fig. 6, Plate 2, was a section about midway along what he had called the Slough gravel bed, from the north of Slough downwards to Isleworth. Here again, for a considerable distance from the outcrop onwards, the Chalk was covered with the Lower Tertiaries, which, with the gravel above them, were full of water; but nearly opposite to Slough they were overlaid by the London Clay beds, on to the surface of which the water passed. Thence it proceeded through the gravel to the Thames between Teddington and Isle-

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worth, and flowing under it, supplied the enormous volume of water found in the gravel beds throughout the southern parts of London. Mr. Harrison.

Mr. G. J. Symons said he should perhaps best show his appreciation of the honour of being asked to open the discussion, by saying nothing about his incompetence. Those who were acquainted with his work knew that it lay almost entirely with water aboveground, whereas the Paper dealt essentially with water underground. They had had the case for deriving a supply from the Chalk put in the strongest possible way. He could not help thinking of the many speeches and papers to which they had listened in that room by the late Mr. Homersham, and how fortunate it was for the cause of chalk-water generally that the mantle of Mr. Homersham had fallen on the shoulders of such a man as Mr. Harrison. But he hoped that what he was about to say would be looked upon rather as coming from one of the general public than from an expert, since his own work had lain upon the surface. The first thing that struck him was, that the fact of there being a large quantity of water found underground did not prove that there was a great amount *available*; it might be a permanent storage, which they could run out, and there would be the end of the matter. It did not by any means follow that because they tapped a large subterranean reservoir they had found a perennial supply. With regard to the quantity of water in the Chalk, as far as he had followed the calculations, they were almost entirely based (not quite, because there was the question of the Wandle, to which he would afterwards refer) upon percolation experiments. No one appreciated more thoroughly than he did the extremely good work which was being done by Dr. Evans, Sir John Lawes, and Dr. Gilbert. He was glad to see Dr. Gilbert present, because if he said something not very polite about the experiments at Rothamsted he was in the presence of one who could correct him if he were wrong. There was a diagram in the Exhibition of the Royal Meteorological Society in the adjoining room representing the percolation gauges at Rothamsted. No one in the world had devoted so much money and care to the question of percolation as Sir John Lawes and Dr. Gilbert, but they themselves knew full well the extreme difficulty which attached to the subject. The problem, or at least an incidental question arising out of the Paper, was the supply of the metropolis, with its five millions of people, with water, and that was a tremendous thing to base simply upon experiments tried over 5 or 6 square feet of surface. The Author had Mr. Symons.

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Mr. Symons. stated, and he quite agreed with him, that a great deal of substantial proof was wanted before such a gigantic project could be developed on so comparatively narrow a basis. The difficulty in connection with the experiments to which he had referred was that every engineer knew that if he dug a hole and took out the earth he could not get it all back again. They had found that out at Rothamsted. They then tried another excellent scheme; they cut down round some cubes of earth, leaving the actual soil untouched, and built walls in concrete on the four sides. Funnels were provided at the bottom so that any water percolating down might go through them and be measured. *Prima facie* it was as good a plan as he could possibly conceive for doing the work, but the difficulty which had occurred to him was this—how about the adhesion between the soil and the brickwork? They surrounded a cube of soil by brickwork. He quite understood that they could grout it in; but if the soil shrank during dry weather, surely it would separate from the four walls, and if so, when the moisture came, was it not probable that it would run down by them? It struck him that a great deal of the percolation took place, not through the cube of earth, but between it and the surrounding walls. No doubt Dr. Gilbert would express his own opinion upon that point. With respect to the question of the Wandle, he was sorry that Mr. Baldwin Latham, who had done so much in measuring water-levels in the Chalk on the Wandle and other streams in Surrey, was absent, and he was afraid there was no chance of the discussion lasting long enough for his return. He was glad, however, to see that some one competent to deal with the matter had placed a diagram of the Wandle upon the wall. With respect to the gaugings, the Author had referred to Mr. Braithwaite's Paper read before the Institution many years ago. Mr. Symons did not wish to find fault, but he had frequently noticed that the Papers read before the Institution were not accompanied by the mass of Tables which he, having a great affection for Tables, should like to see. The data given in Mr. Braithwaite's Paper were extremely limited. Those who had had anything to do with such work knew that taking two or three gaugings, or taking them once a week, gave very little idea of what the perennial flow of a stream was; and unless the diagram of the Wandle was based upon a larger number of observations than those in Mr. Braithwaite's Paper, and in Mr. Harrison's Paper, he did not personally attach any great importance to it. It had always appeared to him that the gauging of English rivers had been ter-

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ribly neglected. He received three times the amount of detail with respect to the Seine, the Po, and other continental rivers, that he did with regard to the Thames. There was one point which he did not at all understand, namely, the enormous increase in the volume of water between Teddington and Kew. Mr. Harrison had alluded to the Seething Wells (the word "seething" certainly did give the idea of something bubbling up) as a sort of out-crop of subterranean water. He was not very well acquainted with the Thames, but he had thought that the Seething Wells were above Teddington, and if so, at any rate some of the water must have got into the river before reaching Teddington. Another difficulty was this. He had spent some time at Richmond, which was a good way below Teddington, and still farther below the Seething Wells, and he confessed that, although he knew nothing about gauging, the volume of the river there did not seem to him to be so enormously large. They had heard a great deal about an enquiry in connection with a proposed weir across the Thames in the neighbourhood of Richmond; and there was no suggestion then that there were these hundreds of millions of gallons going past. It must be rather awkward to gauge there, because the tide came to Teddington, and he did not know how the tidal water was separated from the upland water. There was another point that had occurred to him, on which he did not desire to express any opinion, namely that if the volume of the Thames doubled between Teddington and Richmond, surely the chemical analysis ought to tell something about it. By comparing the constituents of samples taken at the two places, they ought to be able to learn something of the history of the added water. Mr. Symons.

Dr. J. H. GILBERT remarked that as Mr. Harrison had referred to the results obtained by Sir John Lawes and himself, and had founded important estimates upon them, they thought it might be of interest to provide further data than had been already published, and they had accordingly prepared the Tables now exhibited. Mr. Harrison had referred to ten years of percolation experiments; but in the Tables they had given the results of twenty years up to last autumn. The first Table showed the average annual amount of rain in inches, and the percolation in inches, through 20, 40, and 60 inches of soil, and also the complementary amount which represented evaporation. In the second Table would be found the average for each month during the twenty years. The results were given for harvest-years, from September 1st to August 31st. Not only was that method of computation of interest to them as agriculturists, but he thought it ought to be adopted by Dr. Gilbert.

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Dr. Gilbert. those who studied the question of drainage from other points of view. Thus, the second Table showed that the average minimum drainage was in August; and that in September the amount began to increase. If the civil year were taken it would be found that the end of December cut the drainage in the middle of the period of greatest activity; whilst marked decline commenced with March, not April, the point of civil year division. For other purposes, therefore, as well as those of agriculture, the harvest-year was more appropriate than the civil year. But perhaps he ought to say a word as to the observations of Mr. Symons, who had called in question, more or less, the validity of the whole thing. If, as he suggested, there was material drainage between the soil and the walls, the results were of course of very little value; but Dr. Gilbert thought they might be satisfied that the soil would very soon settle sufficiently close to the wall to prevent any such abnormal action.

Taking the average of the twenty years, the minimum drainage was in August, but the details for each individual year showed that it was frequently before August, and very rarely after it; and the recommencement of the drainage was very seldom in August, though with very heavy rain they might have much drainage, and it was not often later than September. If the drainage-beds had been covered with vegetation the average minimum drainage would be earlier than August, and the recommencement would begin later than September. He might be permitted to call attention to one or two of the main results. The first ten years, with an average of about 30 inches of rain, gave 13·21, 13·94, and 12·17 inches, according to the depth of soil, viz., 20, 40, and 60 inches. With a rather less rainfall during the second ten years they had 15·54, 16·38, and 15·05 inches of drainage. That was, with a rather less rainfall there was a larger amount of drainage. There was less through the 60 inches than through the 20 inches of soil. One vitiating element in experiments of this kind obviously was that they were obliged to cut off the drainage at a particular point, so that there was no possibility of a return upwards. If, however, they compared the drainage through the 60 inches with that through the 20 inches, they would find that there was a little less through the greater depth, which was evidence that there had been a return upwards below the point at which it was cut off in the 20-inch gauge; but the fact of its being so little less, he thought, showed that the conditions were not very wide of what they might be under ordinary circumstances. Then as to the larger amount of drainage through the 40-inch gauge, it was found that the Rothamsted

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subsoil was exceedingly variable, and they were able to judge from the composition of the water that passed through it that the subsoil in the 40-inch gauge was probably more gravelly, and therefore there was more percolation; there was, moreover, with more drainage, less nitric acid in it. Dr. Gilbert.

The advantage of having a greater number of years, and full details, was that they were able not only to get a better average, but to study the maxima and the minima, which were of the greatest importance, especially the latter, when they came to consider what was available over a series of years. It would be seen by the first Table, that in 1873–4, with a rainfall of something under 22 inches, the drainage was only 5·74, 5·40, and 3·94 inches. In 1879-80, with a rainfall also between 21 and 22 inches, the drainage was 6·89, 7·39, and 6·50; whereas, in 1878-9, with a rainfall of 41 inches, the drainage was 24·44, 26·03, and 24·38. In 1880-1, with a rainfall of 36·7 inches, the drainage was 22·38, 22·84, and 21·26 inches. Thus, within the harvest-year they might have little more than 5 inches of drainage, or as much as from 22 to 25 or 26 inches. Such results were of great importance to study when considering what would be available under any given circumstances.

The details further showed that although the rainfall obviously had a considerable influence upon it, the amount of drainage was by no means proportional to the rainfall, but depended to a great extent upon the distribution as well. Thus, to give a very obvious example, if they had a given amount of heavy rain during the growing period, there might be no drainage at all; whilst the same quantity during the winter, when there was no vegetation, and little evaporation, might give a very large proportion of drainage. The drainage was, in fact, materially affected by the distribution of the rain, and the drainage and evaporation were, of course, complementary to one another. The Table showed that taking the difference between rainfall and percolation to represent evaporation, they had in two years only 12 inches of evaporation, and in several between 19 and 20 inches; so that there was a great difference in that respect also. According to the average of twenty years, with rather heavy soil free from vegetation, it might be said that the drain-gauges gave about 14 inches. It was difficult to estimate exactly what deduction should be made for vegetation. A large proportion of any area that they had to consider was covered with vegetation. Sir John Lawes and himself had considered that the minimum amount would average 2 inches, as in the case of downs or waste lands, where there was very little vegetation; whereas with a heavy grain-crop, or good

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Dr. Gilbert. mangel crop, there might be an evaporation of 7 inches or more. Taking the average of a large area around London, partly covered with vegetation and partly bare, over a number of seasons, they thought that between 3 and 4 inches should be deducted from the 14 inches of percolation, so leaving 10 or 11 inches. Supposing the average rainfall to be about 30 inches for the twenty years, that left about 19 or 20 inches for evaporation, both by the soil and by vegetation. This agreed very fairly with the results of Dr. Evans and others. Further, in reference to the interpretation of the figures which he had given, it should be observed that the estimated rainfall of the Chalk district was about 27 inches. The rainfall over the twenty years at Rothamsted was, however, 30 inches by the large one-thousandth of an acre gauge, but only 29 inches by the 5-inch gauge. The large gauge recorded a great many small deposits which could not be measured by a small one; and there were also some other irregularities. But if they used the same kind of gauge as that by which the observations of others were mostly made, the ordinary 5-inch gauge, the result would be 29 inches, whereas the estimate for the whole district was only between 26 and 27 inches. Hence the Rothamsted results to which he had referred probably indicated a rather exaggerated amount of drainage for the whole district.

A point to which he wished particularly to call attention was, that the details—the minima as well as the averages—should be studied, if they were to form any trustworthy conclusions from such results. He admitted with Mr. Symons, that there was something artificial in that mode of estimating the drainage of a district, but he knew of no better. He had received a memorandum from Sir John Lawes, calling attention to two or three particular points. The first referred to the fact that, within a mile to the eastward of the gauges, there had undoubtedly been a river before his time, and to the westward there was the Ver, which had gone down immensely during his lifetime, and had often been dry. Then again, the wells had frequently to be lowered, and the water-supply was at any rate lessening, and whether the scheme now in question would or would not affect the waters to the north of London, it was of the greatest importance that nothing should be done to reduce them; for there could be no doubt that they would want all they could get. Sir John Lawes agreed with Mr. Harrison in thinking it extremely desirable that they should have better gaugings of the flow and discharges of the rivers in the chalk district north of London.

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Dr. Gilbert.

Experiments on Rainfall and Drainage at Rothamsted.

Table A.—Summary of results, 20 years.

	Rainfall.		Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
Harvest years, Sept. 1 to Aug. 31.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1870–1	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78
1872–3	28·99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75
1874–5	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52
1876–7	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81
1878–9	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86
1880–1	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2	31·66	32·31	15·81	16·08	14·32	16·50	16·23	17·99
1882–3	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56
1884–5	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45
1886–7	22·63	23·61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83
1888–9	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15·76
1889–90	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69
Averages . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

	Rainfall.		Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
TABLE B.—Averages for each month, 20 Harvest-years.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	2·74	2·86	0·96	0·85	0·75	1·90	2·01	2·11
October	3·07	3·20	1·78	1·74	1·50	1·42	1·46	1·70
November . . .	2·92	3·03	2·24	2·30	2·05	0·79	0·73	0·98
December . . .	2·31	2·42	1·90	2·02	1·81	0·52	0·40	0·61
January	2·34	2·51	1·96	2·25	2·06	0·55	0·26	0·45
February . . .	1·92	2·04	1·44	1·59	1·44	0·60	0·45	0·60
March	1·61	1·74	0·80	0·95	0·86	0·94	0·79	0·88
April	2·12	2·21	0·67	0·74	0·68	1·54	1·47	1·53
May	2·22	2·28	0·60	0·68	0·59	1·68	1·60	1·69
June	2·45	2·52	0·63	0·64	0·60	1·89	1·88	1·92
July	2·96	3·03	0·84	0·85	0·77	2·19	2·18	2·26
August	2·36	2·45	0·56	0·55	0·50	1·89	1·90	1·95
Total . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68
TABLE C.—General Summary, average actual results per annum.								
10 years, 1870–1 to 1879–80 . . .	29·12	30·68	13·21	13·94	12·17	17·47	16·74	18·51
10 years, 1880–1 to 1889–90 . . .	28·91	29·91	15·54	16·38	15·05	14·37	13·53	14·86
20 years, 1870–1 to 1889–90 . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68
TABLE D.—General Summary, average per cent. drainage and evaporation to rainfall.[1]								
10 years, 1870–1 to 1879–80 . . .	..	..	43·1	45·4	39·7	56·9	54·6	60·3
10 years, 1880–1 to 1889–90 . . .	..	..	52·0	54·8	50·3	48·0	45·2	49·7
20 years, 1870–1 to 1889–90 . . .	..	..	47·5	50·0	44·9	52·5	50·0	55·1

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED. Dr. Gilbert.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1870–1.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September	2·11	2·31	0·22	0·06	0·02	2·09	2·25	2·29
October	3·87	4·13	1·07	0·45	0·18	3·06	3·68	3·95
November	1·24	1·40	1·84	1·42	0·71	−0·44	−0·02	0·69
December	2·53	2·65	2·10	1·95	1·07	0·55	0·70	1·58
January	1·40	1·45	0·25	1·12	0·72	1·20	0·33	0·73
February	1·64	1·63	0·91	1·13	0·71	0·72	0·50	0·92
March	1·38	1·50	0·34	0·43	0·23	1·16	1·07	1·27
April	2·82	2·89	0·81	0·80	0·63	2·08	2·09	2·26
May	0·94	0·96	..	0·05	0·04	0·96	0·91	0·92
June	3·89	3·87	1·29	1·15	0·90	2·58	2·72	2·97
July	3·99	3·99	0·81	0·85	0·60	3·18	3·14	3·39
August	0·68	0·77	..	0·01	..	0·77	0·76	0·77
Total	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2.								
September	4·60	4·74	1·82	1·43	1·08	2·92	3·31	3·66
October	0·94	1·12	0·12	0·24	0·23	1·00	0·88	0·89
November	0·60	0·66	0·07	0·14	0·35	0·59	0·52	0·31
December	1·28	1·43	0·82	0·76	0·48	0·61	0·67	0·95
January	4·51	4·67	3·64	3·55	3·13	1·03	1·12	1·54
February	1·36	1·52	0·64	0·77	0·58	0·88	0·75	0·94
March	1·84	2·12	0·92	0·82	0·83	1·20	1·30	1·29
April	1·56	1·61	0·09	0·16	0·13	1·52	1·45	1·48
May	2·88	2·90	0·77	0·75	0·63	2·13	2·15	2·27
June	3·25	3·25	0·77	0·74	0·76	2·48	2·51	2·49
July	2·73	2·72	0·01	0·01	0·01	2·71	2·71	2·71
August	2·28	2·28	0·02	0·02	0·03	2·26	2·26	2·25
Total	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Diff-rence,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep
1872–3.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	1·28	1·37	0·01	0·02	0·01	1·36	1·35	1·36
October	4·59	4·67	3·13	2·68	2·10	1·54	1·99	2·57
November . . .	3·90	4·03	2·85	2·80	2·44	1·18	1·23	1·59
December . . .	3·97	4·16	3·38	3·40	3·04	0·78	0·76	1·12
January	3·53	3·74	2·77	2·73	2·71	0·97	1·01	1·03
February . . .	1·13	1·34	0·71	0·54	0·55	0·63	0·80	0·79
March	1·90	2·05	0·88	1·02	0·80	1·17	1·03	1·25
April	0·54	0·64	..	0·01	0·01	0·64	0·63	0·63
May	1·74	1·87	..	..	..	1·87	1·87	1·87
June	1·66	1·76	..	..	..	1·76	1·76	1·76
July	2·31	2·39	0·62	0·47	0·37	1·77	1·92	2·02
August	2·44	2·64	..	..	..	2·64	2·64	2·64
Total . . .	28·99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4.								
September . . .	2·22	2·38	0·70	0·38	0·20	1·68	2·00	2·18
October	2·61	2·82	0·99	0·83	0·29	1·83	1·99	2·53
November . . .	1·82	1·99	1·08	1·11	0·86	0·91	0·88	1·13
December . . .	0·59	0·71	0·15	0·11	0·04	0·56	0·60	0·67
January	1·78	1·93	1·22	1·35	1·21	0·71	0·58	0·72
February . . .	1·62	1·73	0·85	0·84	0·73	0·88	0·89	1·00
March	0·50	0·65	0 01	0·04	0·03	0·64	0·61	0·62
April	2·00	2·14	0 32	0·29	0·25	1·82	1·85	1·89
May	1·14	1·19	..	..	..	1·19	1·19	1·19
June	1·53	1·59	..	..	..	1·59	1·59	1·59
July	2·82	2·81	0·42	0·45	0·33	2·39	2·36	2·48
August	1·66	1·75	..	..	..	1·75	1·75	1·75
Total . . .	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED. Dr. Gilbert.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1874–5.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	3·48	3·62	0·63	0·25	0·21	2·99	3·37	3·41
October	3·05	3·22	1·52	1·26	1·02	1·70	1·96	2·20
November . . .	2·10	2·34	1·21	1·04	0·69	1·13	1·30	1·65
December . . .	1·61	1·80	1·16	1·34	1·04	0·64	0·46	0·76
January	3·01	3·99	2·87	3·39	2·62	1·12	0·60	1·37
February . . .	0·77	1·18	0·34	0·44	0·38	0·84	0·74	0·80
March	0·75	0·87	0·50	0·57	0·46	0·37	0·30	0·41
April	1·38	1·56	0·09	0·11	0·06	1·47	1·45	1·50
May	2·52	2·74	0·29	0·37	0·30	2·45	2·37	2·44
June	3·15	3·53	0·35	0·26	0·14	3·18	3·27	3·39
July	5·06	5·66	3·29	3·66	3·35	2·37	2·00	2·31
August	0·99	1·10	..	0·03	0·03	1·10	1·07	1·07
Total . . .	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6.								
September . . .	2·46	2·80	0·89	0·83	0·71	1·91	1·97	2·09
October	5·13	5·90	3·72	3·95	3·55	2·18	1·95	2·35
November . . .	3·95	4·43	3·24	3·54	3·26	1·19	0·89	1·17
December . . .	0·90	1·19	0·78	1·01	0·97	0·41	0·18	0·22
January	1·59	1·81	1·46	1·76	1·67	0·35	0·05	0·14
February . . .	2·79	3·05	1·87	2·20	1·94	1·18	0·85	1·11
March	2·42	2·90	1·28	1·74	1·58	1·62	1·16	1·32
April	3·24	3·33	1·36	1·66	1·72	1·97	1·67	1·61
May	0·76	0·78	..	0·04	0·03	0·78	0·74	0·75
June	1·33	1·35	..	..	..	1·35	1·35	1·35
July	1·43	1·46	..	..	..	1·46	1·46	1·46
August	2·83	2·98	0·15	0·14	0·03	2·83	2·84	2·95
Total . . .	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1876–7.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	4·59	5·02	2·30	2·24	2·04	2·72	2·78	2·98
October	1·37	1·52	0·82	1·10	0·96	0·70	0·42	0·56
November . . .	4·00	4·20	2·89	2·99	2·66	1·31	1·21	1·54
December . . .	5·80	6·00	5·21	5·74	5·25	0·79	0·26	0·75
January	4·82	4·99	3·79	4·41	4·11	1·20	0·58	0·88
February . . .	1·98	2·10	0·87	1·19	1·23	1·23	0·91	0·87
March	2·52	2·55	1·01	1·25	1·10	1·54	1·30	1·45
April.	2·68	2·76	1·33	1·61	1·49	1·43	1·15	1·27
May	2·79	2·82	0·44	0·55	0·51	2·38	2·27	2·31
June	1·39	1·44	0·03	0·09	0·10	1·41	1·35	1·34
July	3·23	3·28	0·56	0·51	0·44	2·72	2·77	2·84
August	2·56	2·60	0·38	0·39	0·31	2·22	2·21	2·29
Total . . .	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8.								
September . . .	1·53	1·53	0·21	0·26	0·21	1·32	1·27	1·32
October	1·90	1·95	0·58	0·51	0·39	1·37	1·44	1·56
November . . .	5·15	5·16	4·03	4·20	3·82	1·13	0·96	1·34
December . . .	2·28	2·28	1·74	1·98	1·75	0·54	0·30	0·53
January	1·73	1·75	1·10	1·36	1·20	0·65	0·39	0·55
February . . .	1·77	1·80	1·01	1·20	1·13	0·79	0·60	0·67
March	0·88	0·98	0·27	0·50	0·46	0·71	0·48	0·52
April.	4·01	4·09	2·35	2·52	2·43	1·74	1·57	1·66
May	4·89	4·97	1·48	1·85	1·50	3·49	3·12	3·47
June	2·46	2·51	0·61	0·86	0·76	1·90	1·65	1·75
July	0·64	0·65	0·01	0·03	0·06	0·64	0·62	0·59
August	4·87	4·98	1·33	1·17	1·13	3·65	3·81	3·85
Total . . .	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1878–9.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	1·41	1·46	0·07	0·12	0·11	1·39	1·34	1·35
October	2·99	2·99	1·37	1·39	1·10	1·62	1·60	1·89
November . . .	4·73	4·55	3·77	4·07	3·66	0·78	0·48	0·89
December . . .	1·57	1·60	1·11	1·37	1·54	0·49	0·23	0·06
January	2·46	2·85	2·47	2·65	2·47	0·38	0·20	0·38
February . . .	3·73	3·80	4·44	4·44	4·22	−0·64	−0·64	−0·42
March	1·09	1·18	0·14	0·28	0·26	1·04	0·90	0·92
April	2·61	2·79	1·27	1·51	1·38	1·52	1·28	1·41
May	3·45	3·48	1·22	1·39	1·30	2·26	2·09	2·18
June	5·49	5·55	2·15	2·24	2·18	3·40	3·31	3·37
July	4·17	4·24	1·83	1·97	1·81	2·41	2·27	2·43
August	6·47	6·56	4·60	4·60	4·35	1·96	1·96	2·21
Total . . .	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80.								
September . . .	3·07	3·13	1·11	1·00	0·92	2·02	2·13	2·21
October	0·76	0·82	0·22	0·42	0·43	0·60	0·40	0·39
November . . .	0·71	0·81	0·20	0·12	0·10	0·61	0·69	0·71
December . . .	0·78	0·82	0·41	0·49	0·44	0·41	0·33	0·38
January	0·55	0·55	0·48	0·61	0·46	0·07	−0·06	0·09
February . . .	2·88	2·90	2·36	2·59	2·30	0·54	0·31	0·60
March	1·10	1·13	0·04	0·09	0·09	1·09	1·04	1·04
April	2·14	2·16	0·49	0·53	0·43	1·67	1·63	1·73
May	0·71	0·74	..	0·02	0·03	0·74	0·72	0·71
June	1·94	1·97	0·01	0·01	0·02	1·96	1·96	1·95
July	5·22	5·26	1·35	1·23	1·06	3·91	4·03	4·20
August	1·02	1·07	0·22	0·28	0·22	0·85	0·79	0·85
Total . . .	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

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Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1880–1.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	..	5·69	5·86	3·96	3·93	3·78	1·90	1·93	2·08
October . .	..	5·88	5·94	4·47	4·45	4·07	1·47	1·49	1·87
November .	..	2·87	2·92	2·25	2·39	2·14	0·67	0·53	0·78
December .	..	3·45	3·47	2·82	2·85	2·68	0·65	0·62	0·79
January . .	1·07	1·12	1·14	1·01	1·12	1·32	0·13	0·02	–0·18
February .	3·35	3·33	3·70	3·43	3·71	3·29	0·27	–0·01	0·41
March . .	1·99	2·10	2·15	1·66	1·78	1·65	0·49	0·37	0·50
April. . .	0·92	0·97	1·00	..	0·01	0·03	1·00	0·99	0·97
May . . .	1·28	1·39	1·38	..	0·01	0·04	1·38	1·37	1·34
June . . .	1·53	1·62	1·63	0·01	0·02	0·04	1·62	1·61	1·59
July . . .	1·67	1·73	1·76	..	0·01	0·01	1·76	1·75	1·75
August . .	5·47	5·70	5·82	2·77	2·88	2·21	3·05	3·26	3·61
Total . .	17·28	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2.									
September .	2·01	2·09	2·17	0·81	0·81	0·70	1·36	1·36	1·47
October . .	2·84	2·93	3·05	1·76	1·73	1·53	1·29	1·32	1·52
November .	3·29	3·45	3·47	2·49	2·50	2·29	0·98	0·97	1·18
December .	4·16	4·33	4·38	3·95	4·04	3·65	0·43	0·34	0·73
January . .	1·42	1·55	1·57	1·24	1·38	1·23	0·33	0·19	0·34
February .	1·88	1·99	2·02	1·15	1·13	1·01	0·87	0·89	1·01
March . .	1·38	1·48	1·57	0·45	0·58	0·49	1·12	0·99	1·08
April. . .	3·71	3·82	3·92	1·87	1·77	1·57	2·05	2·15	2·35
May . . .	1·95	2·01	2·07	0·74	0·85	0·74	1·33	1·22	1·33
June . . .	3·79	3·90	3·93	1·25	1·15	0·99	2·68	2·78	2·94
July . . .	1·95	2·05	2·09	0·10	0·12	0·10	1·99	1·97	1·99
August . .	1·97	2·06	2·07	..	0·02	0·02	2·07	2·05	2·05
Total . .	30·35	31·66	32·31	15·81	16·08	14·32	16·50	16·23	17·99

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall, the difference is entered as a minus quantity.

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	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1882–3.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·15	2·21	2·29	0·71	0·57	0·40	1·58	1·72	1·89
October . .	6·39	6·46	6·52	5·46	5·55	5·10	1·06	0·97	1·42
November .	3·24	3·29	3·44	2·49	2·65	2·41	0·95	0·79	1·03
December .	3·07	3·03	3·28	3·00	3·22	2·98	0·28	0·06	0·30
January . .	3·19	3·28	3·30	2·89	3·11	2·81	0·41	0·19	0·49
February .	4·18	4·28	4·34	3·76	4·01	3·70	0·58	0·33	0·64
March . .	0·75	0·76	0·89	0·02	0·06	0·09	0·87	0·83	0·80
April . .	1·40	1·43	1·48	0·28	0·26	0·22	1·20	1·22	1·26
May . . .	1·77	1·84	1·89	0·63	0·70	0·62	1·26	1·19	1·27
June . . .	2·10	2·17	2·23	0·13	0·11	0·09	2·10	2·12	2·14
July . . .	4·03	4·16	4·21	1·44	1·42	1·25	2·77	2·79	2·96
August . .	0·71	0·78	0·84	0·01	0·06	0·05	0·83	0·78	0·79
Total. .	32·98	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4.									
September .	3·83	3·94	3·99	1·63	1·43	1·32	2·36	2·56	2·67
October . .	2·38	2·48	2·49	1·39	1·50	1·38	1·10	0·99	1·11
November .	3·35	3·46	3·52	2·77	2·71	2·47	0·75	0·81	1·05
December[1] .	0·92	1·07	1·16	0·79	0·97	0·95	0·37	0·19	0·21
January . .	2·51	2·55	2·56	1·87	1·81	1·65	0·69	0·75	0·91
February .	1·31	1·38	1·42	0·72	0·92	0·86	0·70	0·50	0·56
March . .	1·59	1·64	1·66	1·13	1·18	1·10	0·53	0·48	0·56
April . .	1·69	1·74	1·79	0·24	0·18	0·19	1·55	1·61	1·60
May . . .	0·58	0·61	0·64	0·04	0·09	0·11	0·60	0·55	0·53
June . . .	2·43	2·46	2·50	1·09	1·06	1·04	1·41	1·44	1·46
July . . .	2·34	2·40	2·44	0·16	0·10	0·10	2·28	2·34	2·34
August . .	1·51	1·56	1·60	0·03	0·05	0·04	1·57	1·55	1·56
Total .	24·44	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-inch Funnel Gauge.	5-inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1884–5.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·05	2·11	2·18	1·29	1·26	1·11	0·89	0·92	1·07
October . .	1·60	1·64	1·70	0·52	0·47	0·41	1·18	1·23	1·29
November .	1·86	1·87	2·05	0·72	0·69	0·61	1·53	1·36	1·44
December .	2·96	3·06	3·06	3·22	3·23	3·01	–0·16	–0·17	0·05
January . .	2·88	2·94	2·99	2·59	2·60	2·43	0·40	0·39	0·56
February .	2·73	2·84	2·85	2·43	2·60	2·45	0·42	0·25	0·40
March . .	1·30	1·19	1·46	0·63	0·71	0·67	0·83	0·75	0·79
April . .	2·76	2·81	2·88	1·04	1·05	0·92	1·84	1·83	1·96
May . . .	2·73	2·82	2·88	0·91	0·98	0·87	1·97	1·90	2·01
June . . .	2·68	2·71	2·76	1·46	1·52	1·46	1·30	1·24	1·30
July . . .	0·35	0·35	0·38	0·01	0·03	0·04	0·37	0·35	0·34
August . .	1·52	1·56	1·59	..	..	..	1·59	1·59	1·59
Total . .	25·42	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6.									
September .	4·19	4·31	4·39	1·55	1·42	1·25	2·84	2·97	3·14
October .	4·64	4·72	4·82	3·41	3·51	3·14	1·41	1·31	1·68
November .	3·65	3·73	3·77	3·41	3·59	3·31	0·36	0·18	0·46
December .	1·19	1·21	1·33	1·00	1·04	0·91	0·33	0·29	0·42
January . .	2·96	2·80	3·44	3·58	3·91	3·92	–0·14	–0·47	–0·48
February .	0·55	0·55	0·61	0·58	0·71	0·60	0·03	–0·10	0·01
March . .	1·42	1·44	1·59	0·83	0·93	0·69	0·76	0·66	0·90
April . .	1·83	1·88	1·96	0·59	0·73	0·58	1·37	1·23	1·38
May . . .	4·08	4·16	4·24	2·12	2·29	1·93	2·12	1·95	2·31
June . . .	1·14	1·15	1·23	0·08	0·12	0·10	1·15	1·11	1·13
July . . .	2·31	2·38	2·42	0·21	0·14	0·11	2·21	2·28	2·31
August . .	1·12	1·13	1·22	0·01	0·02	0·03	1·21	1·20	1·19
Total .	29·08	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1886–7.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	1·38	1·43	1·51	0·01	..	0·01	1·50	1·51	1·50
October . .	3·77	3·91	3·94	2·16	1·99	1·74	1·78	1·95	2·20
November .	2·62	2·71	2·77	2·40	2·62	2·43	0·37	0·15	0·34
December .	4·12	4·17	4·21	2·46	2·58	2·36	1·75	1·63	1·85
January . .	2·22	2·20	2·39	2·32	3·83	3·78	0·07	–1·44	–1·39
February .	0·89	0·90	0·95	0·48	0·55	0·51	0·47	0·40	0·44
March . .	1·64	1·63	1·76	0·21	0·22	0·18	1·55	1·54	1·58
April . .	1·10	1·12	1·19	0·13	0·22	0·18	1·06	0·97	1·01
May . . .	2·22	2·25	2·35	0·04	0·06	0·07	2·31	2·29	2·28
June . . .	0·67	0 68	0·71	0·43	0·50	0·45	0·28	0·21	0·26
July . . .	0·71	0·69	0·79	..	0·01	0·01	0·79	0·78	0·78
August .	0·95	0·94	1·04	..	..	..	1·04	1·04	1·04
Total .	22·29	22·63	23·61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8.									
September .	2·99	3·02	3·11	0·36	0·26	0·19	2·75	2·85	2·92
October . .	1·57	1·57	1·69	0·35	0·26	0·20	1·34	1·43	1·49
November .	3·27	3·34	3·41	2·70	2·82	2·65	0·71	0·59	0·76
December .	1·54	1·53	1·66	1·19	1·31	1·23	0·47	0·35	0·43
January . .	0·80	0·81	0·94	0·46	0·56	0·50	0·48	0·38	0·44
February .	0·97	0·88	1·03	0·27	0·43	0·45	0·76	0·60	0·58
March . .	2·97	2·98	3·13	3·16	4·05	3·99	–0·03	–0·92	–0·86
April . .	2·03	2·02	2·14	0·76	0·93	0·88	1·38	1·21	1·26
May . . .	1·21	1·23	1·28	0·07	0·09	0·09	1·21	1·19	1·19
June . . .	4·74	4·75	4·87	2·38	2·49	2·40	2 49	2·38	2·47
July . . .	3·59	3·75	3·86	0·76	0·83	0·68	3·10	3·03	3·18
August . .	3·14	3·23	3·38	1·50	1·55	1·41	1·88	1·83	1·97
Total .	28·82	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1888–9.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	0·86	0·87	1·03	0·08	0·12	0·09	0·95	0·91	0·94
October . .	0·96	0·98	1·09	0·07	0·03	0·02	1·02	1·06	1·07
November .	4·34	4·37	4·45	3·51	3·51	3·29	0·94	0·94	1·16
December .	1·57	1·61	1·69	1·51	1·60	1·54	0·18	0·09	0·15
January . .	1·16	1·19	1·29	0·82	1·06	0·82	0·47	0·23	0·47
February .	1·82	1·80	1·95	1·53	1·74	1·61	0·42	0·21	0·34
March . .	1·77	1·80	1·89	0·83	0·85	0·82	1·06	1·04	1·07
April . .	2·36	2·39	2·47	0·35	0·42	0·35	2·12	2·05	2·12
May . . .	4·85	4·90	5·00	3·06	3·32	2·85	1·94	1·68	2·15
June . . .	1·28	1·21	1·38	0·41	0·53	0·47	0·97	0·85	0·91
July . . .	5·58	5·59	5·67	2·43	2·58	2·42	3·24	3·09	3·25
August . .	2·02	2·08	2·18	0·04	0·06	0·05	2·14	2·12	2·13
Total .	28·57	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15·76
1889–90.									
September .	2·31	2·36	2·44	0·77	0·73	0·63	1·67	1·71	1·81
October . .	3·51	3·57	3·62	2·45	2·47	2·28	1·17	1·15	1·34
November .	1·12	1·14	1·21	0·93	0·98	0·91	0·28	0·23	0·30
December .	1·36	1·40	1·46	1·29	1·46	1·34	0·17	..	0·12
January . .	2·86	2·94	2·94	2·42	2·62	2·52	0·52	0·32	0·42
February .	0·74	0·75	0·82	0·48	0·60	0·54	0·34	0·22	0·28
March . .	2·71	2·75	2·78	1·71	1·83	1·69	1·07	0·95	1·09
April . .	1·23	1·22	1·31	0·01	0·06	0·06	1·30	1·25	1·25
May . . .	1·34	1·34	1·38	0·12	0·10	0·10	1·26	1·28	1·28
June . . .	2·33	2·36	2·40	0·06	0·03	0·04	2·34	2·37	2·36
July . . .	4·41	4·49	4·56	2·76	2·61	2·54	1·80	1·95	2·02
August . .	2·38	2·42	2·51	0·16	0·11	0·09	2·35	2·40	2·42
Total .	26·30	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

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NOTE BY DR. GILBERT.—These Tables, of which the first four were placed on the wall during the discussion, contain the results of the experiments on Rainfall and Drainage at Rothamsted for twenty harvest-years (September 1 to August 31), 1870–71, to 1889–90 inclusive. The rainfall is given as registered both by a 5-inch funnel-gauge, and by a specially made gauge of $\frac{1}{1000}$th of an acre area; also by an 8-inch gauge since the beginning of 1881. The drainage, or percolation results, represent the amounts of the rainfall passing through rather heavy uncropped soil, as shown by three "drain-gauges," each of $\frac{1}{1000}$th of an acre area, one with 20 inches, one with 40 inches, and one with 60 inches depth of soil, in its natural state of consolidation. Table A shows, for each of the twenty harvest-years, the total amount in inches of rainfall by each gauge, of drainage or percolation, through 20 inches, 40 inches, and 60 inches of soil, and the difference approximately representing the evaporation. The evaporation was in all cases calculated on the rainfall shown by the $\frac{1}{1000}$th of an acre gauge. Table B shows, for each of the twelve months of the harvest-year, the average rainfall, drainage, and evaporation over the twenty years. Tables C and D are general summaries of the average results for the first ten, the second ten, and the total period of twenty years. The succeeding twenty Tables give, respectively, for each of the twenty harvest-years, the rainfall, drainage, and evaporation, for each month, and the total for the year. It should be explained that the funnel portion of the $\frac{1}{1000}$th of an acre rain-gauge is constructed of wood, lined with lead, the upper edge consisting of a vertical rim of plate-glass bevelled outwards. The rain is conducted by a tube into a galvanized iron cylinder underneath, and when this is full it overflows into a second cylinder, and so on into a third and fourth, and finally into an iron tank. Each of the four cylinders holds rain corresponding to $\frac{1}{4}$ an inch of depth, and the tank an amount equal to 2 inches. Each cylinder has a gauge-tube attached, graduated to read to 0·002 inch, but which can be read to 0·001 inch. Small quantities are transferred to a smaller cylinder, with a gauge-tube graduated to 0·001 inch. The three drain-gauges were constructed by digging a deep trench along the front, gradually undermining at the depth required, and putting in plates of cast-iron, with perforated holes, to support the mass. The iron plates were kept in place by iron girders, and the ends of the plates and of the girders supported by brickwork at the back and the two sides. Trenches were then dug round the block of soil, and it was gradually enclosed by walls of brick laid in cement. Below the perforated iron bottom a zinc funnel of the same area as the block of soil was finally fixed, and the drainage water collected and measured in galvanized iron cylinders, with gauge-tubes, as in the case of the rain. These soil drain-gauges being kept without vegetation, their results are not directly applicable for estimating the amount of percolation over a drainage-area more or less covered with vegetation, and it had been suggested that they should be so covered. But this would sacrifice important results; and as the amount of evaporation is very different with different kinds of vegetation, the results with only three drain-gauges, and these with one description of soil and of varying depth, would also be inapplicable for the purpose of directly estimating the percolation of a district. In 1874 a series of eighteen drain-gauges was arranged for the investigation of the influence of various crops, but unfortunately the specially made glazed stoneware cylinders, 24 inches diameter and 60 inches deep, were found not to be watertight, and hence the attempt was abandoned. About forty years ago, however, experiments of quite another kind were made at Rothamsted for several years in succession, to determine the amount of water

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Dr. Gilbert. given off by plants during their growth, those selected including various individual agricultural plants, the mixed herbage of grass-land, and also evergreen and deciduous trees. The results afforded valuable data upon which to form a judgment as to the probable amounts of evaporation due to vegetation; and the indications so obtained, together with those of direct percolation experiments with and without vegetation, constitute the only evidence of a purely experimental kind at present available, as the basis of general estimates. It is, however, obviously desirable that estimates so founded should be studied in connection with those arrived at in other ways, such as by the gaugings of rivers and of wells.

Mr. Hopkinson. Mr. JOHN HOPKINSON, of St. Albans, had devoted considerable attention to the subject of the rainfall in Hertfordshire. The annual average during the ten years 1880–1889, at eighteen stations in the county, each of which had a consecutive record for that period, was 26·74 inches. In order to ascertain the correctness of this result for the ten years, he took the average of all the gauges in Hertfordshire from which he had collected returns, the number varying from 26 to 30 during the ten years, and found it to be 26·78 inches, *i.e.*, only 0·04 inch above the mean for the eighteen stations. He thought they ought not to be content with observations for a short series of years, or even for so few as ten, but to extend them over as long a period as possible; and in order to ascertain the average rainfall for the half century 1840–1889, he had taken the averages of five continuous series of records, namely, for the first ten years of the half century the record of one gauge; the second ten years the records of two gauges; the third ten years, those of seven; the fourth, of twelve; and the fifth, of eighteen. Those eighteen records correctly represented the average for the whole county; but the difficulty was that the smaller number of gauges might be in certain localities in which they had more or less rainfall than the average. He had found by taking the ratios of the records in the previous years to those in the last ten, that from the position of the gauges they would give rather less rainfall than if all the eighteen had been in use for the half century. The annual rainfall, taking the records as they were for the fifty years, was 26·43 inches, and the deduction which should be made to get the correct amount for the half century would bring it down to 26·16. The mean rainfall for the last ten years thus appeared to have been about $\frac{1}{4}$ of an inch, or $2\frac{1}{2}$ per cent., in excess of that during the half century. It might possibly be contended that the correction he had made was too great, so he would take round numbers and say that the mean in Hertfordshire for the half century was $26\frac{1}{4}$ inches, or 2 per cent. less than the rainfall for the last ten years. Having arrived at that deter-

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mination, all they had to do for the entire area was to ascertain the rainfall for the last ten years, and deduct from it 2 per cent. Accordingly he had taken the largest number of continuous records they had over the whole of the area, which he had divided into four nearly equal portions; (1) the Kennet, (2) the Thames between Wallingford and Windsor, (3) the Colne, (4) the Lea. Mr. Hopkinson.

TABLE SHOWING THE MEAN ANNUAL RAINFALL IN THE CHALK AREA OF THE THAMES BASIN WEST AND NORTH OF LONDON, 1880–89.

River Basin.	District.	Rain.	Station.	Rain.
		Inches.		Inches.
Western Area, 26·08 inches. — Kennet, 29·68 inches.	Marlborough	31·05	The Green and Mildenhall	31·05
	Hungerford	29·70	Denford Park	29·70
	Newbury	30·44	Welford Park	30·44
	Reading	27·54	Englefield	29·75
			Russell Street	25·34
	Ock	29·13	Letcombe Regis, Wantage	29·13
Thames, 26·47 inches.	Thames above Kennet	23·87	Wallingford Castle	23·87
	Thames below Kennet	27·74	Henley-on-Thames (Greys)	27·10
			Henley-on-Thames (Assenton)	30·70
			Maidenhead	25·42
	Loudwater	25·15	High Wycombe	25·15
Northern Area, 27·18 inches. — Colne, 29·04 inches.	Bulbourne	29·30	Cowroast, Tring	29·60
			Berkhampstead	29·00
	Gade	28·64	Great Gaddesden	28·07
			Nash Mills, Hemel Hempstead	28·85
			Kensworth	28·32
	Ver	28·44	Rothamsted, Harpenden	28·64
			Gorhambury, St. Albans	28·36
	Colne below Ver	29·77	Watford	28·56
			Rickmansworth	30·98
Lea, 25·32 inches.	Mimram	25·58	Welwyn	26·56
			Datchworth	24·61
	Rib	25·04	Therfield	25·55
			Throcking	24·52
	Ash	25·98	Much Hadham	25·98
	Lea below Mimram	24·68	Bayfordbury, Hertford	25·04
			Red House, Ware	24·33
	Mean of Districts	27·63	Mean of Stations	27·58

The gauges were nearly equally distributed over this area. In the Kennet district they were situated at Marlborough, Hungerford, Newbury, and Reading (two); in the Thames district between Wallingford and Windsor, at Wantage, Wallingford Castle, Henley-on-Thames (two), Maidenhead, and High Wycombe; in the Colne district at Tring, Berkhampstead, Great Gaddesden, Hemel Hempstead, Kensworth, Harpenden, St. Albans, Watford, and Rickmansworth; and in the Lea district at Welwyn, Datchworth, Therfield,

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Mr. Hopkinson. Throcking, Much Hadham, Hertford, and Ware. The results of those he had grouped so that they had a mean for areas of tolerably equal size. The grouping of the areas was: in the Kennet, Marlborough, Hungerford, Newbury, and Reading; in the Thames, the Ock river-basin, the Thames between the Ock and the Kennet, the Thames between the Kennet and the Loudwater, and the Loudwater river-basin; in the Colne, the Bulbourne, the Gade, the Ver, and the Colne river-basin between the Ver and the London Clay district; and in the Lea, the Mimram, the Rib, the Ash, and the Lea river-basin between the Mimram and the London Clay district. The result of those divisions was that the mean rainfall for the Kennet was found to be 29·68 inches; for the Thames, 26·47; the Colne, 29·04; and the Lea, 25·32; giving for the whole area 27·63 inches. If they wished to ascertain the rainfall for the half century they had simply to reduce these figures by 2 per cent., and the result would be 27·08, or in round numbers 27 inches; and he thought it would be found that 27 inches was as nearly as possible the mean rainfall over the whole of the chalk area to the north and west of London. Having determined that, it was required to ascertain the amount of percolation corresponding to this rainfall, and for that purpose they could take the experiments of Mr. Dickinson and Dr. Evans—the longest series that had been published—extending (to go no farther back than the half century) over forty-four years, and the result, through 3 feet of the ordinary soil which covered the Chalk, from October 1840 to September 1884, was 6·94 inches out of a rainfall of 28·18 inches. The period was sufficiently long for this to be accepted as a fair average. The mean rainfall during the decade 1880 to 1889 was 28·85 inches; deducting 2 per cent., the mean for the half century would be 28·27 inches, which was not very different from that for the forty-four years. Therefore he thought they could rely upon the 6·94 or 7 inches percolation as being tolerably correct. At Lea Bridge during twenty-two years, from 1852 to 1873, Mr. Charles Greaves determined the average percolation through 3 feet of soil, such as usually covered the Chalk within the Thames basin in Hertfordshire, to be 6·87 inches out of a rainfall of 25·84 inches. He had also the rainfall of the nearest gauges to Lea Bridge which were on the Chalk. It was rather less, and therefore the percolation, if taken on the chalk area over the twenty-two years, would have been rather less. Still, there was a percolation of under 7 inches through the ordinary soil which covered the Chalk, so that the experiments of Mr. Greaves at Lea Bridge agreed fairly well with those of Dr. John

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Evans and of the late Mr. Dickinson at Nash Mills. Averaging them, it would be seen that they gave a percolation of 6·91 inches out of a rainfall of 27·01 inches, and as he had shown that to be about the average rainfall over the whole area, it might be assumed that the average percolation was a little under 7 inches. With regard to the experiments at Rothamsted, of course there was an uncertainty arising from the ground being kept hoed and free from vegetation. Growing plants absorbed a great deal of moisture, as to which Dr. Gilbert had given them a good approximation. The water which percolated into the Chalk was usually assumed to get out of the reach of evaporation when it had passed through 3 feet of soil, but he did not think they ought to consider that to be the case. Professor Ansted had expressed his opinion that there was no practical limit to the capillary action of chalk, and he had made experiments showing that water would certainly rise in it 16 feet. Von Pettenkofer had found the evaporation from an oak tree during the whole period of its summer growth to be more than 8 times the amount of rain falling on the area covered by the tree, the excess being drawn up by the roots from a great depth. A considerable portion of the land referred to was wooded, and there must be a much greater draught upon the underground water where the ground was covered by trees than where it was bare, or nearly so. They were not, therefore, justified in considering that water which percolated through 3 feet of soil was free from evaporation and absorption by vegetation. Nor could they depend for their water-supply upon the average rainfall and the average percolation for the whole of the period under consideration; the experiments of Dr. John Evans and the late Mr. Dickinson, at Nash Mills, had shown that for six years in succession they might have to rely upon 4¼ inches of percolation through 3 feet of soil, for five years upon 4½ inches, for four years upon 4 inches, for three years upon 3 inches, which was only about one-quarter of the average which Mr. Harrison depended upon in his calculations. With regard to the available area of percolation, Mr. W. Whitaker had constructed maps bearing upon that point. He had given the proportions in sheet 46 S.E. of the old 1-inch Ordnance map, which comprised the chalk area between Hitchin and St. Albans from north to south, and Dunstable and Hertford from west to east. All but 8 square miles were marked by Mr. Harrison in his map as bare chalk. Mr. Whitaker's computation was that out of 209 square miles, bare chalk occupied about 76 square miles, chalk

Mr. Hopkinson.

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Mr. Hopkinson. covered by permeable beds 39, chalk protected by mixed beds 67, and chalk protected by impermeable beds 27 square miles. In this map there were 8 square miles of Tertiary beds, chiefly the three outliers shown at the north-east corner of Mr. Harrison's map; so that out of 200 square miles shown by Mr. Harrison as bare chalk, about 67 square miles were protected by mixed beds, and 21 by impermeable beds. If they considered mixed beds as half permeable and half impermeable, at least one-quarter must be deducted from the area shown as bare chalk. If that proportion were maintained over the whole of the chalk area in the basin of the Thames to the north and west of London, a question upon which he hoped Mr. Whitaker would enlighten them, they might have to rely for a long series of years upon an average annual percolation of three-eighths of that assumed by Mr. Harrison, namely, half the percolation on three quarters of the area; for six years in succession upon one quarter; and for three years in succession upon one-sixth; and he did not think they could safely base their estimate of minimum supply from the percolation during a longer period than three years.

Mr. Lucas. Mr. JOSEPH LUCAS remarked that Mr. Hopkinson had given some Hertfordshire rainfall averages over a period from 1840 to 1884. He did not happen to catch the figures, but they would be of particular interest in connection with a series of gaugings made by the Grand Junction Canal Company of the springs at Wendover. These gaugings began in 1841, and the whole series was published in 1884 by the Meteorological Society in the form of a diagram in the report of the Committee on the Decrease in Water-Supply. He should like to ask Dr. Gilbert, whether he and Sir John Lawes kept the register of the variation of any well at Rothamsted in connection with percolation-gauges?

Dr. Gilbert. Dr. GILBERT replied that they had not done so in connection with percolation-gauges; but they had now and then to lower their wells.

Mr. Lucas. Mr. JOSEPH LUCAS said that the water in the Banstead well was no doubt sustained by the beds connected with the chalk rock, below which there were frequently bands of marl. With regard to the well-defined gathering-grounds from which springs issued, mentioned in the Paper, he had surveyed the whole range of the Chalk from Berkshire for a distance of 100 miles, considerably beyond Cambridge, and contoured the entire area to every 10 feet of elevation, during the last thirteen or fourteen years, and he found that the area of supply to the Wendover springs, of which the gaugings were well known, might be measured accurately. It so happened that the water-ridge was singularly sharply

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defined round that little basin; but in order to give some idea of the extremely complex nature of those underground water-basins in the Chalk, he would mention that if a line were drawn round that contributing to the Wendover springs, taking the water-ridge as the limit of it, it would be found to measure 2·8 square miles. The whole contributing area, however, was in reality larger. The Wendover springs broke from the Totternhoe stone, which was a sandy bed of a somewhat marly character, but in the main calcareous, which lay in the Lower Chalk. The Totternhoe stone formed an inclined plane, and the water issued from the lowest point of its outcrop, namely, the bed of the valley. It presented over a considerable area an upper surface for the reception of whatever water might filter down to it from the Chalk above. The chalk lying on the top of the Totternhoe stone happened to be almost impermeable. It was known as the Grey Chalk, and might be taken as 40 feet thick, and acted generally as a retaining bed. Above it there was a bed of perhaps the whitest chalk in the whole formation, reaching another 40 feet, and lying immediately beneath the marls, which were about 3 feet thick, and which underlay the Melbourne rock. The Melbourne rock was the base of the Middle Chalk. On section No. 2, Plate 2, where the words "Chiltern Hills" occurred, was the well sunk by the late Mr. Homersham, the only one Mr. Lucas knew of which traversed the whole of the Middle Chalk. It started about 6 feet above the Chalk rock, and it went to the base of the Melbourne rock. In most places the water-line in the Chalk rose until it met the base of the Melbourne rock, or a little above it, and then it turned and fell over the other way. Frequently the water-line dropped through the White Chalk from the point where it broke through the Melbourne rock, until it came to the Grey Chalk, when there was very slow percolation, and the gradient was lower. The Grey Chalk, being slightly permeable, passed the water down to the Totternhoe stone, which acted as a pipe, conducting it laterally to the springs at its outcrop in the bed of each valley. In this case it drained an area slightly larger than that indicated by the water ridges on the map. The area so obtained in the case of the Wendover springs was 4·6 square miles, and for the forty-four years, 1841 to 1884, both inclusive, the annual mean flow might be taken from the diagram at 177 cubic feet a minute, which represented a mean percolation of almost exactly 9 inches per annum. With regard to the Wandle, he believed that the figures given in the Paper were too large. He had himself gauged that river through one winter

Mr. Lucas.

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Mr. Lucas. at nearly every mill daily, and he was inclined to doubt whether a mean of 20,000,000 gallons a day was exceeded by the Wandle. Wherever he had been able to get a gauging which could be converted into the form of percolation on a given area, 8 or 9 inches was generally the maximum indicated by it. Therefore with regard to the Author's further question as to what became of the difference between the quantity gauged at the springs and that shown by the percolators, he thought another fallacy was involved. Fifteen or sixteen years ago when Professor Ansted was speaking in that room, and expressed his belief that the water was re-evaporated from the Chalk, everybody laughed at him. Now, however, Mr. Lucas had entirely come round to that opinion. He considered that the large quantity to be accounted for between the 8 or 9 inches which could be proved to flow from the springs, together with the 2 inches that might pass under the Tertiaries, and the amount indicated by Sir John Lawes' percolators, was evaporated. Percolation did not take place regularly, but at intervals, and in the meantime they had no record whatever of what was going on in the way of evaporation from the soil. That a very large evaporation took place could not be doubted, because on a hot day it could be seen. However, inasmuch as London actually pumped the whole of the water that came down to it under the tertiary strata, and they could tell pretty well what was being pumped, he thought it might be set down as 10,000,000 gallons a day. It might be a little more, but he did not think it would in any case much exceed 2 inches over the whole of the chalk area, above the line that might be drawn from north to south, through the east-end of London. West of that line the whole quantity pumped, about 10,000,000 gallons a day under London, would give 2 inches rainfall on the area of the Chalk. Therefore with regard to the question as to what became of the difference, it was certainly not to be looked for underground. Whether it was possible, according to any plan adopted by Sir John Lawes and Dr. Gilbert, to determine the amount re-evaporated from the Chalk he did not know, but it seemed to him a very important point. The Author had mentioned two lines of disturbance as passing through London. He considered the east and west disturbance to be exceedingly well proved, but that running north and south had not, in his opinion, the nature of a fault. The faults at Tandridge Hill and Titsey were very well marked on the ground; but there was no evidence of their crossing the outcrop of the Chalk; at least he could not find them again at the base of the tertiary strata. He did not think they ran far. With regard to the north and south disturbance, he believed

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Professor Prestwich had abandoned it long ago. It seemed to him that in the low-level gravels, whose bottoms ran below the level of the rivers, a large quantity of water might be and undoubtedly was obtained, which had penetrated from the river; but he would trust no such bed to afford water which could not be seen before it went into the gravel. High-lying gravel, which was above the level of the rivers, and was dependent on its own rainfall, was not, in his opinion, capable of yielding a large supply, and, if it did, the water would always be open to all the objections that applied to that obtained from shallow wells. Mr. Lucas.

Mr. Santo Crimp observed that, as he had gauged the Wandle daily for three years, he was able to give some general results of his observations. The object of the Author apparently was to show that the objection of Dr. Evans quoted in the Paper, "that Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river or filter into the tunnels from the bed of the river," and that "the flow of the Thames below will be diminished by the same amount of water as that abstracted by means of the tunnels," was groundless. In order to prove his case Mr. Harrison had first referred to the experiments of Mr. Dickinson, and he stated that the amount of percolation through the chalk gauge was 10·65 inches; but if he remembered rightly two gauges were employed by Mr. Dickinson, one filled with chalk and one with soil, and the average amount of percolation through the latter was only 6½ inches. He thought, therefore, that if a part of the chalk had been removed from the other gauge and a layer of soil corresponding with the soil on the top of the chalk as ordinarily met with substituted, the amount of percolation through would have been much less. The Author had referred to the want of a record of gaugings from a well-defined gathering-ground, suggesting the River Wandle, and said that measurements should be made at Hackbridge. He would point out that in that case the water pumped at the Croydon waterworks would not be included, because it was distributed upon the Beddington sewage farm, and the amount not evaporated there entered the river at a lower point. The extent of the gathering-ground had been given by Mr. Harrison as 56 square miles. In order to ascertain this, it was necessary to make a hydro-geological survey, which was undertaken by Mr. Baldwin Latham, and Mr. Santo Crimp did the work for him. He was sorry that Mr. Baldwin Latham was not present Mr. Crimp.

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Mr. Crimp. to give the results himself. As a matter of fact the area of Chalk drained by the Wandle was 64 square miles, and not 56 as stated in the Paper. He took the gaugings of the Wandle at Merton, and the total drainage-area above that point was 84 square miles in extent, including about 20 square miles of London Clay. It was possible, however, to estimate the amount of water due to the London Clay by making separate gaugings of Graveney Brook, which drained a well-defined area of London Clay. The average rainfall during those three years, as shown by the nine gauges scattered over the chalk-area, was 38·8 inches. At Greenwich during the same period—1879–80–81—it was 17 per cent. in excess of the average. It followed, therefore, that if the gaugings of the Wandle had been made during the three years when the rainfall was 17 per cent. less than the mean, the results would not have been the same as they were when Mr. Santo Crimp gauged the river. During those years the average volume discharged by the Wandle at Merton was at the rate of 31½ million gallons per day, equal to a depth of 9½ inches over the entire drainage-area. Without the water due to the Graveney and the remainder of the London Clay area, the amount was 26·82 million gallons a day, equal to a depth of 10·6 inches from the chalk drainage-area—a figure in close accordance with Mr. Dickinson's 10·65; but, as he had pointed out, the rainfall was 17 per cent. in excess during those three years, and that was a mere coincidence. During the same time, the drainage from the Graveney area amounted to a depth of 7 inches per annum. Making the necessary reductions in order to get the mean discharge of the Wandle (perhaps a somewhat difficult matter) he thought the figures would be:—the depth run off from the entire watershed would be equal to 7¾ inches; from that of the Wandle alone, 8⅔ inches, equal to 23 million gallons per day as against 30 millions estimated by the Author. He believed he was right in saying that the average amount running off from the Thames watershed was equal to 7⅓ inches over the entire area. That was taking the mean discharge at Teddington, together with the quantity abstracted by the water companies, at 1,000,000,000 gallons per day, and all these figures were in fair accordance with each other. It seemed to him, therefore, that by over-estimating the volume of water discharged by the Wandle and under-estimating the drainage-area, the Author had very much over-estimated the amount available for water-supply in the upper reaches of the Thames.

Mr. Lucas. Mr. JOSEPH LUCAS said he had omitted to state, with regard to

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the area of the Wandle, that he had measured the apparent chalk area 52½ square miles; but as to the real gathering-ground indicated by the subterranean water ridge, 54¼ square miles, there being a slight feed on the eastern side, 8 inches upon that area gave 17,250,000 gallons a day. Mr. Lucas.

Mr. J. C. Hawkshaw remarked that a great deal of interesting information had been given as to the quantity of water likely to be found in the district under consideration, but there was one point that had not been touched upon. In providing for the water-supply of London, or indeed of any other town, it was necessary to consider how the withdrawal of any quantity of water from a given place would affect the supply of the neighbouring district. He thought there could be no question that the water stored in the lower beds of the Chalk and in the beds overlying and adjoining them where they dipped beneath the surface, was continuous with that stored in the upper beds of the Chalk, and he did not see how it was possible to pump any large amount from the lower storage without affecting the level of that in the upper beds, from which the population of the district would draw their supply. It was no more possible to do so than it would be to draw water from the bottom of a cistern without affecting the surface-level at the top of it or the overflow if there was any. It might be interesting to state briefly what was the effect of pumping water from the Mountain Limestone at the Severn Tunnel. The Mountain Limestone had this in common with the Chalk, that a large proportion of the water falling on its surface was conveyed to the sea by underground channels. Where the tunnel passed from beneath the Severn under the land in Monmouthshire, it mainly ran through beds of Millstone Grit and overlying Triassic Red Marls. Beneath these was the Mountain Limestone which rose to the north of the tunnel, becoming the surface-rock of a considerable district in south-east Monmouthshire. The bottom of the tunnel only touched the limestone-rock at one place, and there it cut through a fissure, from which a volume of water was discharged into the works sufficient to flood them and stop the progress for twelve months, until enough pumping power was provided to deal with it. As soon as the water was pumped out, all the wells and springs in the neighbourhood were dried. There could be no question that this was due to the pumping, because when the water was dammed back in the works it rose again to its old level in the springs and wells. It appeared to him that if any large quantity was abstracted from the Lower Chalk the same thing Mr. J. C. Hawkshaw.

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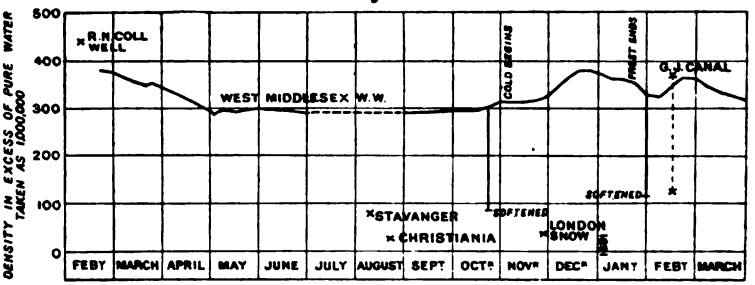
Mr. J. C. Hawkshaw.

would happen to a district more or less large, the area depending on the quantity of water which was pumped.

Mr. Blakesley.

Mr. T. H. BLAKESLEY wished to say a few words on a question raised by the Author and touched upon by Mr. Symons. The Author had spoken of the admixture of water from the Chalk in the gravel of the London basin. There could be no doubt that the water gathered from the Thames for the supply of London contained not only a great deal of chalk-water, but also much that came from other strata. He based that view upon the fact that the water from the Chalk was invariably much heavier than that from the gravel. From a number of observations he was quite certain that the London water-supply contained a good deal which was derived from the gravel, though the bulk came

Fig. 2.



from the Chalk. Chalk-water almost invariably had a specific gravity more than 400 parts in 1,000,000 greater than that of pure water, whereas the London water very rarely reached that density. *Fig. 2* showed the quality from this point of view of the water from his cistern in West Kensington, which was supplied by the West Middlesex Waterworks. Various isolated cases were also given for comparison. It would be seen that the minimum density occurred during the summer, increase taking place about September or October. It exceeded 300 in 1,000,000 all through the winter, and it was less than 300 in 1,000,000 during the summer. He had obtained similar data throughout other years. The chalk-water of Folkestone was in the winter 429 parts in 1,000,000 heavier than pure water.[1] That from the chalk well at the Royal Naval College, Greenwich, was in February 439. The softened Canterbury water was only 101. The Grand Junction

[1] The probable error in the densities here given may be taken as 1 in 1,000,000. —T. H. B.

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Canal water was 369 in February of this year, and softened to 123. The Rouen water, also from limestone, was 362 during spring. The purest water-supply he had ever met with was that of Christiania, which was only 26 parts in 1,000,000 in excess of pure water in density during summer. The result of applying the softening process was also shown in *Fig. 2*. The quality of the water had only been touched slightly upon by the Author; but, as affecting the London supply, it was a most essential matter. Some of the specimens to which Mr. Blakesley referred were remarkably soft. The Author had, he thought, very much understated the capacity of the chalk to hold water. He had given it as two gallons in a cubic foot, but Mr. Blakesley considered that three gallons would be nearer the truth. He had carefully weighed pieces of chalk, and after keeping them under water for many days, weighed them again; and so estimated the quantity that could be contained in them; he then allowed them to dry, and weighed them again. An interesting point was, that the chalk which had been as much as twenty-three days under water would return to its original weight in twenty-four hours after being taken out, showing the extraordinary power it possessed of giving up moisture to a dry atmosphere. He had no doubt that the surface of the chalk discharged a large quantity into the air in this way. Of course, it would also absorb moisture, even without rainfall, in a damp atmosphere; but he thought that an estimate of supply, based upon rainfall without considering evaporation, must necessarily be incorrect. Mr. Blakesley

Dr. JOHN EVANS remarked that the Paper appeared to him to be remarkably vague. All the Author's statements were carefully said to be "approximate," and great difficulty would be found in ascertaining in what manner he arrived at his results. With regard, for instance, to the variation in the Thames, when he found that on July 8th the increment was 49,000,000 gallons, on July 10th 131,000,000 gallons, on the 22nd 196,000,000 gallons, and in April 250,000,000 gallons, he could not imagine how by any process of reasoning these figures could be supposed to represent anything like the average increment in the volume of the Thames at the points indicated. He also found variations from 137,000,000 gallons per day in April down to 17,000,000 gallons on the 22nd of July, whereas on the 10th there had been 43,000,000 gallons. It was impossible to obtain any information from such figures as to what the average increment would be. There was another point which appeared to be of doubtful propriety, namely, the revival of views which had been exploded more than Dr. Evans.

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Dr. Evans twenty years ago. For example, the Author quoted the statement of Mr. Homersham—which had been disputed in that room many times, and so far back that his memory could hardly recall it, that there were no less than 1,200 square miles of chalk sloping towards Watford. That was referred to as a statement on which reliance could be placed. In another part of the Paper it was said that the whole area north-west of London was only that 1,200 square miles, and that Watford was nearly 200 feet above Ordnance datum. He could not imagine the frame of mind in which those two statements could be placed side by side as being equally credible. Then the area of the gathering-ground of the Wandle was also quoted from Mr. Homersham as being 56 square miles. Mr. Homersham had, however, pointed out that if that were the case, in order to obtain the ordinary flow of the Wandle, 29 inches of rain must be absorbed into the ground and delivered out as the surplus quantity after all that nature required had been done. But, inasmuch as in most years 29 inches did not fall, he did not see in what manner the Author could explain the discrepancy. Another point also appeared to have been entirely lost sight of—namely, what was known as the angle of friction of water in a porous body. Statements had been made as to the height of many points of the streams above ordnance datum, but no proper allowance had been made for the difficulty that water had in passing through the Chalk. It was evident from some of the sections, as for example, that of the Gade sloping towards Watford—which by-the-way was not strictly accurate, inasmuch as the inclination was higher as they got towards the chalk-marl, and towards Tring—that the flow of the river was on an average 14⅓ feet per mile. Now unless the angle of friction—that was, the elevation of water which was caused by its passage through the rock being impeded—was greater than 14 feet per mile, the river would simply disappear altogether and could not exist upon the surface. The ponds referred to in the neighbourhood of Burnham and Slough appeared to him to be simply sheets of water formed at certain points in beds of gravel above the London Clay. Then came the question as to the amount of rain which found its way into the earth in order to feed those rivers, and there he would rather not rely on any figures of his own, but would take those so carefully prepared by Sir John Lawes and Dr. Gilbert. He found from them that for twenty years the average percolation through the 16 inches of soil had been 3·89 inches in the summer months, namely, from the beginning of April to the end of September, whereas in the winter

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months it was 9·72 inches, making a total of 13·61 inches. But there was this peculiarity about the gauges of Sir John Lawes and Dr. Gilbert, that although evaporation was taken into account they did not in any way allow for the water taken up in the process of vegetation. The soil was kept carefully free from weeds and all growth, and the results therefore did not represent the amount which actually found its way through land in a state of cultivation, or covered with grass. It was known from experiment that a grain of wheat in growing could absorb, if it were given to it, more than the total amount of rain that fell, and he believed Sir John Lawes and Dr. Gilbert estimated that at least they must allow 2 or 3 inches of water in summer for the crops on the ground. Dr. Evans thought that 3 inches was not an over-estimate. During the months he had included in the winter half-year, from October to March, there was also generally a certain amount of absorption for purposes of vegetation. If the 3 inches in the summer were deducted there would be for the summer percolation 0·89 inch, closely corresponding with the Tables he had brought before the Institution some years ago.[1] In the winter months, deducting only the 1 inch for evaporation, there would be 8·72 inches, giving a total of 9·61 inches. It would be borne in mind that the minimum shown on Sir John Lawes' and Dr. Gilbert's Tables was only 5·81 inches, from which, again, the amount necessary for vegetation must be deducted, and that would bear out very closely his suggestion that not more than 4 or 5 inches of the rainfall were available on a chalk surface as a constant source of supply. The Rivers Pollution Commissioners in their sixth Report took as an average 6 inches, with which he did not disagree; but even then they could not rely upon that quantity being always available for the purpose of supplying water, and he thought that they must not count on more than 4 inches. The Commissioners calculated the area of land in the chalk country which might be used within 30 miles of London for the purpose of supplying water at 850 square miles. Taking the average at 4 inches (and he had known the percolation to be not so much as 3 inches) that would give 130,000,000 gallons per diem, which, he maintained, was hardly sufficient for the vast metropolis of London. But after all he did not think that the question as to the amount of rain which percolated into a porous soil like chalk was of so very much importance in the present discussion. It

Dr. Evans.

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 220, and vol. xlv. p. 208.

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Dr. Evans. appeared to him that the Paper was founded on a considerable amount of assumption in various directions. He found, for instance, that two vast expanses of gravel at a low level, and saturated with water, were assumed to exist in the neighbourhoods of Datchet and Slough, together covering 90 superficial miles, and that in each of those there was said to be an underground river. He should like to ask if any one had ever seen those underground rivers or such a continuous expanse of water-bearing gravel over that large extent of country? There was no doubt a considerable spread of alluvial or diluvial beds of brick-earth and gravels at various elevations, but to believe that there was such an enormous reservoir of pure gravel as was laid down in the Paper, with subterranean rivers flowing through it, both north and south of the Thames, transcended his limited powers of imagination. No doubt there was a large delivery into the Thames out of the beds of gravel from Maidenhead down the river as far as Staines; and, indeed, he thought the Paper showed that there were no means by which the water might escape in the direction of the sea. It should be borne in mind that assuming those beds of gravel to exist, the water in them must be continuous, so that what they took from one part would be replaced by water from other places coming through the ordinary channels between the stones. The Author had shown that that water could not escape in the direction of London. Then the question arose what really became of it? Mr. J. C. Hawkshaw had pointed out that it was impossible to pump from the bottom of a cistern without affecting the surface. Even if it were filled with gravel, the interstices would hold a certain amount of water, but in pumping from the bottom the upper surface would be lowered. He believed that the opinions he had enunciated, in a lecture delivered before the Institution, some years ago,[1] were not very far from being correct. But granting that Mr. Harrison's views were just, how would any amount of pumping from the reservoirs prevent the water from the neighbourhood flowing in, and so robbing the stream precisely according to the amount taken from the tunnel? Viewing generally the history of the streams flowing through porous rocks like chalk, it must, he thought, be evident that those streams represented the excess of the rainfall over what had been absorbed by processes of nature or of art. First, it was necessary to take into consideration the evaporation, which, as was known from experi-

[1] "The Theory and Practice of Hydro-Mechanics." A Series of Lectures. Session 1884–85.

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ments both on open surfaces and on moistened soils, amounted to a considerable quantity in each year; and in addition to that, in the case of chalk, it would be necessary to allow for a certain amount of moisture being brought up from the lower depth by means of capillary attraction; for though a large amount might be evaporated from the surface, there would always be more or less moisture coming up from below, keeping the ground within a certain distance of the surface slightly damp. Secondly, it was needful to take into account that large amount of water which was consumed in the process of vegetation. There could be no doubt that an enormous percentage of the weight of plants in the green state consisted of water which had been absorbed from the soil. Thirdly, there was a possibility of leakage below ground, by the water finding its way to the sea, or to some stream not immediately within the watershed. No doubt all along the southern coast there was a constant delivery of water from the Chalk into the sea, without any stream being fed by it, and the intercommunication in the pores and fissures of the Chalk, between the water flowing seawards and the sea itself, was evidenced by the well at Brighton, which rose and fell in accordance with the state of the tide. He thought it would be evident to all, that assuming that there was a leakage going on—and there was no doubt always a tendency in the water that supported those streams to be working down-hill—the subterranean waters still maintained the water in the Chalk at a certain level, so that the streams did not cease to flow. Anything that abstracted from that underground water, even supposing it was on its way to the sea, would of necessity affect the streams on the surface. They could not take away from the bottom of the cistern without lowering the level of the upper surface; they could not, by means of a cock, draw off from the bottom of an overflowing cistern without affecting the overflow. He therefore maintained, in the first place, that what water there was in those marvellous beds of gravel, and in those underground rivers, was already being delivered into the Thames by means of natural vents, and secondly that whatever they took from it, whether by tunnels or otherwise, though possibly they might by that means get a purer water than they would from the river, would be virtually so much abstracted from the Thames itself.

Dr. Evans.

Mr. W. Whitaker said the Author had spoken of the abrupt alteration in the dip of the strata between Epsom and the Hog's Back as likely to interfere with the passage of the water. Mr. Whitaker denied the abruptness of the alteration. As a matt-

Mr. Whitaker.

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Mr. Whitaker. of fact it was very slow and gradual; it led from a dip on the east of from 3° to 5°, to what was an abrupt dip of 30° or 40° on the west; but between those extremes there was every gradation, and he was sure that the change was not enough to stop altogether, though it might to some extent retard, the passage of water; and there was a great difference between stopping and retarding. There was certainly an east and west disturbance (by which he presumed was meant a disturbance running from east to west) east of London; but he could not agree with the Author in describing it as a great one. It was a fault which had a maximum throw of 150 feet, and therefore could only result, as far as the Chalk was concerned, in throwing one part of the Upper Chalk against another part of the same stratum, and that the water would be stopped by it was very doubtful; certainly he did not think it would justify the Author's statement that the disturbance would effectually bar its passage; it might do so in one place and not in another. The Author had also made a slip in speaking of the edge of the great chalk basin; he had referred to the Lower Chalk as rising to the highest level, but that was not the case; it might rise nearly to it, but the highest levels of the chalk were hardly ever formed of the lower beds. In the Lower Chalk he included what was now known as the Middle. The Upper Chalk came on along the top of the great escarpment, and the Lower Chalk rose to a fairly high level, but not to the highest. The statement that the London Clay overlaid the Chalk was one against which he had often protested. The London Clay never touched the Chalk anywhere, and Mr. Harrison knew it as well as he did, because he had qualified the statement further on by noting other beds between. As to the 1,200 square miles alluded to by Dr. Evans, it had struck him as peculiar that a large area of Chalk from the west to the basin of the Lea should total 1,200 square miles, and that only a bit of it, which was little more than the Colne drainage, should be given by another speaker as rather more than 1,200 miles. Of course Mr. Harrison's figures were right, but Mr. Homersham's could not be. The gathering-ground of 1,200 square miles, to which Mr. Harrison referred, did not consist almost entirely of bare chalk, as shown on his maps, and on all general geological maps. On the contrary, over a great part of the tract in question, perhaps to the extent of about one half, the Chalk was irregularly covered by a set of deposits of a more or less clayey nature, which must greatly retard the access of rain to it, and lessen the quantity that soaked in. These deposits were shown on the Drift Editions

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of some of the Geological Survey Maps; but their mapping was not yet finished over the western part of the district. The maps to which Mr. Hopkinson had alluded, as constructed to show the areas where the Chalk was bare or capped only by permeable beds, and where it was protected from surface-action by beds of mixed or doubtful character, or by impermeable strata, could be made only from such Drift Maps. Some of these maps were exhibited and described a few years ago,[1] and it was hoped that the Geological Survey would exhibit an extended set at the National Congress of Hygiene to be held in London next August. The Author had spoken of the water crossing the London Clay barrier at Datchet. That was another mistake, but it was one for which Mr. Harrison was not in any way answerable. The statement was founded on the Geological Survey map, but even geological surveyors occasionally made mistakes. Mr. Whitaker had acknowledged the mistake in print;[2] it was simply made owing to the absence of information. As a matter of fact the River Thames entered the Tertiary barrier close to Bray, below Maidenhead, instead of at Datchet. It again touched the Chalk near Windsor and again entered it at Datchet. When he originally mapped that country, about thirty years ago, there was no evidence on the subject, and he did not like to colour Tertiaries under the gravel of the low ground above Windsor, but took the safer plan of keeping the lines well up, and so showed it as Chalk. He was a little at issue with the Author, who quoted Mr. Homersham, about the chalk water from the north of London and from the west being effectually barred from reaching the sea by a disturbance or fault running north and south across the London basin below London. He could see no trace of any such fault. There was certainly a slight disturbance up the valley of the Lea, roughly speaking. It seemed to open somewhat the fissures in the upper part of the Chalk, making the passage of the water more free than it might have been. The result was important, for it enabled the East London and New River Companies to draw a large quantity of water from wells in the Chalk in the valley of the Lea. It also affected the supply of the mills and other establishments in that district. He believed

Mr. Whitaker.

[1] 1884. "Geological Magazine," Decade iii. vol. i., pp. 23–29, "Proceedings of the Norwich Geological Society." "Journal of the Society of Arts," vol. xxxii. pp. 847–851, and "Health Exhibition Literature," vol. viii. pp. 364–373.

[2] "The Geology of London and of Part of the Thames Valley" (Geological Survey Memoir), vol. i. pp. 176, 177 (1889).

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Mr. Whitaker. that the competition had not resulted in any cessation of supply to any good well in the valley. So that the slight disturbance, instead of barring the passage of the water, seemed to have facilitated it. Professor Prestwich also had been quoted; he had, however, given up any north and south fault there. As he had stated in his book, "The Water-bearing Strata of London," it was a disturbance affecting not the Chalk, but the Tertiary beds. Mr. Whitaker thought Mr. Harrison had been a little misled on that point, having extended Professor Prestwich's statement from the Tertiary beds to the Chalk. The faults alluded to by Mr. Lucas were quite local, and might affect the supply at one house, but have nothing to do with another half a mile off, so that they would be of no moment whatever in regard to the large question of water-supply. The Author had spoken of another fault westward of Kensington as indicated by the levels of the chalk-water in artesian wells. He failed to see that the evidence bore out the conclusion, because a fault might not affect the level of the water in the wells. The difference spoken of by the Author, that the water was 30 or 40 feet lower eastward of Kensington than westward, was susceptible of explanation from the fact that the former tract was nearer the area of excessive pumping than the latter. He thought that few people realized the enormous quantity of water pumped from the Chalk in private wells in London; it was 8,000,000 or 10,000,000 gallons per day, or even more, though the exact amount was not known. Probably that was enough to account for the lowering of the water-level locally. It had been stated by many engineers and others years ago that the water-level under London had sunk enormously in consequence of the increased number of wells and the continuous pumping. Professor Prestwich in his book had spoken not merely of faults, but of disturbances generally, and the disturbances referred to by Mr. Harrison were so very gentle that there was no need to call in such a thing as a fault, which implied a fracture with disturbance, to explain them. Dr. Evans had alluded to those peculiar variations in the increment of the stream between Maidenhead and Windsor. If that increment fluctuated between 137,000,000 gallons and 17,000,000 gallons per day, he did not see how they could depend on it for a supply to London, which wanted 100,000,000 gallons or more every day. The Author had divided the large spread of gravel into two, but Mr. Whitaker did not quite understand the line of division, which was drawn a little north of Hampton. A few years ago he was at the waterworks at that place, and he had evidence

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that instead of there being one sheet of gravel at Hampton there were two at different levels, with a slight outcrop of London Clay between. The result was that the gravel on the south, from which the Water Companies obtained their supply, was isolated from the larger sheet on the north, and the division would be a little south of where it was placed on Mr. Harrison's map. How far that outcrop of London Clay went he could not say. In the early geological survey, they did not attempt to refine as now. The "gravel" along that part of the Thames meant simply the area which was nearly all covered with gravel; but in which there might be patches of London Clay at the surface here and there. He questioned whether the water in this gravel came from any underground source. To a large extent at least he believed it was got by filtration from the Thames, and he thought that the Water Companies' engineers were of the same opinion. He knew that Mr. Harrison had the opinion that the Bagshot Sand contributed to the water; but it could only do so to a small extent, because between it and the gravel there was a slight outcrop of London Clay all round, so that all the water flowing out of the Bagshot sand would be thrown out by springs, some of which might flow into the gravel. He could not quite understand how the water from some of those chalk districts on the north, coming apparently down the Colne, got into the higher gravel at Slough as distinct from the lower ground of Maidenhead and Windsor. It seemed to him that some of it must go against the ordinary flow of the river. He imagined that most of the water would pass through the gravel by the nearest way to the neighbouring river, and that it would go southward and not towards Slough. The most astonishing thing in the Paper, however, was the increment said to be received by the Thames between Teddington and Kew. He did not understand whether the figures had been taken over any extent of time, or whether they wanted checking; but if 400,000,000 gallons a day in a dry season got into the Thames in that neighbourhood, he could not see how the river was ever very low. He understood that the minimum flow of the Thames in the neighbourhood of Hampton was about 300,000,000 gallons a day, and if that was not enough to keep the river-bed from being dry, another 400,000,000 gallons a day would do it. An idea had occurred to him that some of the water might have filtered through the gravel from the higher part of the river where there were some bends, as would be seen from the map, and where possibly there might be some underground channels. Mr. Harrison

Mr. Whitaker.

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Mr. Whitaker. referred to the fine chalk springs at Havant, in Hampshire. He should like to know whether it was quite certain that they yielded as much as 200,000,000 gallons per day. The Portsmouth people had enlarged their works, and it might have been thought that if the water could be got so easily they need not have done so. There was undoubtedly an enormous supply there from the Chalk. The question of the water coming from the synclinal of the Hampshire chalk-basin was affected by the fact that close to Havant was an anticlinal axis, and if that had any effect, it ought to be to cut off the supply, which apparently it did not do. The anticlinal axis that he meant was a rise from under the Tertiary beds, and was visible to the eye from the railway for a long distance—the great ridge of Portsdown, in which it was possible to walk almost on the same bed of chalk up and down both sides and on the top. The springs were on the south, and there was a large chalk area further northward. There must be some communication, and it seemed as if that great disturbance were powerless at all events effectually to bar, though it might perhaps retard, the flow of water from the north, and if that were so, it might be the same in other places. Each case would have to stand on its own merits. He had to examine the cutting between Maidenhead and Twyford on the day after the Paper was read, not in connection with the water, but merely to see the character of the chalk, and he found no trace of any hole through which water could go. He did see in one place a well in the Chalk, the water in which was 20 feet or 30 feet down; that was not low for the dry season. He supposed that a wet season might have some effect in bringing the water-level in the Chalk nearly to the surface in that part. He agreed with Mr. Evans, that the water in the ponds near Burnham was held up by the London Clay, or other Tertiary beds under the gravel. Most of those mentioned by the Author in the same connection were, he imagined, filled by water from the gravel, rather than by chalk-water. He need not enter into the question of the age of the Valley Gravels of the Thames. Glacial phenomena, however, appeared to have a fascination for every one, Mr. Harrison included. He had thought that the brick-earth and the Thames gravel might have been formed during the glacial period, from wash from the sands and chalk. Mr. Whitaker considered that the brick-earth was newer than the glacial period, and was probably formed more from the London Clay than from anything else. As to the steadiness of the water through the Tertiary Sands from the well at Bushey, he did not quite understand the remark in the Paper, because the well was

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in chalk, and the steadiness of the water was that of chalk-water, rather than of tertiary-water. He should have been glad if some engineers would have said something on the general question at issue. On that question they were greatly indebted to the Author. He had dealt with a subject on which most people were afraid to write; he had freely expressed his opinions, and given them an opportunity of discussion. As a matter of feeling, he went with the Author to a large extent, having long thought that it would be well if London could get an underground supply from its own district. The surrounding area was so exceptional in its character, and had interests so great and varied, that it was doubtful whether London would be able wholly to supply itself from underground sources. The question was most important, and he should like to see all classes, landowners, engineers, Water Companies, and County Councillors approach it in a large spirit. Mr. Whitaker.

Mr. JAMES MANSERGH observed that Dr. Evans and Mr. Whitaker had anticipated much of what he had intended to say, and he would only make a few remarks with regard to the subjects of percolation, and of the gauging of the Thames. Dr. Gilbert had stated that the beds at Rothamsted were kept free from crop, and that in order to obtain the real percolation from the general country, some deduction, varying between 2 and 7 inches, would have to be made. It appeared to him that this was a serious drawback to the usefulness of the observations. All the work at Rothamsted was so skilfully and carefully done that he had no doubt it would be possible for Sir John Lawes and Dr. Gilbert to arrange a percolation-gauge with a growing crop upon it, so that this error might be eliminated. It would manifestly be of great advantage if such an improvement could be effected. Mr. Mansergh.

He would now say a few words on the real point of the Paper. On page 3, the Author quoted from Dr. Evans' lecture on physiography in 1885, as follows:—"Mr. J. T. Harrison's schemes for obtaining water by means of tunnels in the chalk of the Thames valley, merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished by just the same amount of water as that abstracted by means of the tunnels." He then went on to say: "It cannot be doubted that apprehensions of this kind, unless they are removed or proved to be groundless, will always be sufficient to cause the overthrow in Parliament of any proposal to supply London with water from the Chalk formation. It would consequently be a useless waste of time

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Mr. Mansergh. to submit a Paper on the subject to the Institution, unless the Author of it were prepared to give, as he believes, convincing proofs that no such disastrous consequences would result from the proposal." This being the real object of the Paper it was difficult to understand how the proposition could seriously be made to abstract from the ground the water which was stated to be flowing from it into the Thames between Teddington and Kew. Surely the residents on the banks of the river at Twickenham, Richmond, and the places below, would protest in the strongest terms against this reduction of volume. They would certainly consider the consequences to be "disastrous." Already they grumbled terribly at the taking of less than 100,000,000 gallons a day by the water companies; but the Author proposed to reduce the flow by a quantity sufficient "for the supply of London and its suburbs for centuries to come." This sentence would probably be considered by the general public as the most important one in the Paper. It came just after a statement as to the "increment between Teddington and Kew in August, 1887, and November, 1890," and pointed to the figures given as being the measure of the quantity available without harm to the river. It was consequently of the greatest moment that there should be no doubt whatever as to the accuracy of these figures, and he would like to ask the Author how the gaugings were made. He thought there would be great difficulty in doing it satisfactorily, on account of the complications caused by the influx of the tidal water. For the purposes of a bill which was before Parliament last session, careful observations were made at a point about half-way between Teddington and Kew bridge, in order to find the exact height of the rising and falling water every quarter of an hour throughout a whole cycle of tides. Now they showed that out of the twenty-seven tides there were—

8	when the least discharge was *not* maintained for 15 minutes.				
6	„	it *was* maintained for 15 minutes.			
5	„	„	„	„ 30	„
5	„	„	„	„ 45	„
2	„	„	„	„ 1 hour 45 minutes.	
1[1]	„	„	„	„ 2 hours 45	„

He wished to ask the Author—

1st. If it might not be fairly assumed that all the water over and above the least quantity was tidal water?

[1] The correctness of this observation was questioned.—J. M.

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2nd. How he distinguished between this tidal water and the increment from the gravel? Mr. Mansergh.

3rd. Might not some of this increment (possibly a great part of it) be simply water that flowed into and out of the ground as the tides rose and fell?

He considered that a few gaugings made under these exceptionally difficult conditions were an insufficient basis upon which to build the whole fabric of this Paper.

Major Lamorock Flower wished to offer a few remarks with reference to the Banstead Well. He had occasion some years ago to make certain observations with a view of supplying that district with water, and he could state as a fact that the Banstead Well did not vary much in level, notwithstanding the condition of the springs at Carshalton. He thought that Mr. Harrison had put it too deep. Major Flower never found a greater difference of level than 3 feet between the driest and the wettest season. With regard to supplying London from underground water, he would ask whether they should not be somewhat careful of the surface from which that water was drawn. Having had charge of the Lee watershed for the last twenty years, he knew the value of looking after the surface, and also the distribution of sewage, which might, through fissures, get down to a lower level. A similar remark would apply to the gravel beds, and it was one of the objects which Water Companies had in view in opposing the disposal of sewage from the Lower Thames Valley on the beds at Molesey. Such matters, though they might appear trifles, were really worthy of consideration. Major Flower.

Mr. R. F. Grantham said it would be remembered that in 1877 there was a proposal to obtain water for London from the chalk for drinking purposes and fire-extinction. In the following year his father was called upon to investigate the effects of pumping in two wells in the Chalk in Essex where 2,000,000 gallons were being pumped per day, and he found that the result between the years 1869 and 1878 was to permanently lower the level of the water 14 feet; he also found that the wells in the neighbourhood about a mile round were considerably affected. It was impossible, in the face of a fact like that, to avoid apprehending that any large abstraction of water from the Chalk must influence the outflow from it into the rivers and streams all round. So with regard to the Slough underground reservoir mentioned by Mr. Harrison. In carrying out the sewerage works at Slough they became well acquainted with the district between Slough and Datchet to the east, and between Slough and Dorney to the Mr. Grantham.

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Mr. Grantham. west; and they found in the low-lying ground the existence of a considerable quantity of subsoil water as described by the Author. They had, in consequence, to lay iron pipes for the outfall sewer for 1,200 yards, and to pump night and day in order to build the tanks, which were 16 feet deep. All round the neighbourhood the subsoil water stood at about 4 feet below the surface, and on opening two holes a mile apart there was found a difference in level of the underground water from 7 feet to 8 feet, or very nearly the inclination the Author had stated. As the water-level was so near the surface, and it was flowing eastwards towards the Colne, it seemed to him that if either of the alternative culverts were laid, as proposed by Mr. Harrison, one from the Hampton Reservoir to Salt Hill, and from Salt Hill to Farnham Royal, and the other between Langley Marsh and Uxbridge—that the abstraction of water caused by them would seriously influence the quantity in the River Colne between Staines and Uxbridge. It would be remembered that two or three years ago the Grand Junction Waterworks Company proposed to lay a culvert to Dorney. The Slough sewage farm was laid out on the north side of Dorney Common, and the Eton sewage-farm was close by. They found there a sharp bed of gravel, at least 5 or 6 feet deep. The sewage pumped on to that gravel went into the soil, and never came out again. He thought it was as well to point that out, because if a culvert were laid anywhere near that place at a great depth, the water from it would not be particularly palatable.

Mr. Wentworth-Sheilds. Mr. F. WENTWORTH-SHEILDS observed that the scheme described in the Paper had been objected to on the ground that if the lower strata were tapped the higher beds would be drained of water; but he thought this would not be the case if the Author's premises were correct, namely, that the water flowed from the Upper Chalk through the porous beds next the Thames, and lipped over into the river. This would be analogous to a barrel fed from an inclined shoot, in which case the water would overflow on the barrel edge, and a portion might be intercepted immediately above it without in any way affecting either the flow down the shoot or the water-supply at the top of it. So it would be in the soil, as the upper levels would similarly remain unaltered if the water which welled over into the river were intercepted. It was for the Author's opponents to prove that he was wrong in that supposition upon which his scheme was based; and if Mr. Harrison had shown that there was really an increase of some four hundred millions of gallons in the flow at Kew, above that at Teddington, where no subsidiary stream came in to account for

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it, that circumstance would go far to make good his case. He presumed that Mr. Harrison's gaugings were taken at low-water; and if his data were correct, that the water would probably be collected in a long intercepting culvert with open joints, placed near and parallel to the river in the neighbourhood of Hampton. Mr. Wentworth-Sheilds.

Professor HENRY ROBINSON had no doubt that many like himself, concerned in the question of the water-supply in London, had been collecting information which would soon be brought before a public tribunal, so that their mouths were closed on the present occasion. Many criticisms had been passed on Mr. Harrison's views, and he should prefer to abstain from adding to them. There happened, however, to come within his professional experience, a few years ago, a report made by Mr. Harrison to the Local Government Board with the view of showing the large amount of water to be obtained from the Chalk by driving a tunnel, which was called the Black Pot Tunnel. From investigations which Professor Robinson had made in connection with one of the London Water Companies, and from the information given in Mr. Whitaker's geological memoirs, the Black Pot Tunnel, shown in the report as driven in the Chalk, was practically in an impervious stratum far above the Chalk, and therefore any hypothesis based upon the assumption that the tunnel could be driven at that spot, as Mr. Harrison supposed, was an entire fallacy. Professor Robinson.

Mr. W. TOPLEY did not propose to follow Mr. Whitaker and Dr. Evans in the geological details which they had laid before the meeting, and with which he agreed. He might, however, in justice to Mr. Harrison, point out that some of Mr. Whitaker's criticisms, although just and right, did not touch the real point of the Paper. It did not, for example, much matter, in considering Mr. Harrison's scheme, what his interpretation was of some of the disturbances east of London, and whether they prevented the water going to the sea or not. The real problem was whether there was water in the gravel, and whether it could be utilized for the supply of London, and on that question he agreed in part with Mr. Harrison. He was by no means sure that the quantity was as large as Mr. Harrison had stated; but it was no doubt considerable. If they tapped the water above the intakes, they would prevent it going into the Thames, or being taken by the London Water Companies, but nothing would be gained in quantity. Mr. Whitaker had made a point in stating that there was, north of Hampton, a rise of the London Clay, or something of that kind, which made a division between the two gravels, and he said that Mr. Topley.

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Mr. Topley. the water was got by the Water Companies from the south side of the line of division. But the real point of the Paper was the curious statement as to the amount which got into the Thames between Kingston and Kew. That was on the north side of the disturbance, as Mr. Whitaker had admitted. If it were true, as the Author had said, that there was so large an increment between those two points, surely some of it could be utilized. It might be serious for the people at and below Richmond, but it would not affect the question as to the present state of the London Water Companies, because the water would be taken below the point at which the supply was now obtained. That, he thought, was the crucial point of the Paper, and he should have been glad if the engineers who had spoken had given more attention to it. It was curious that the Author had referred to a statement of Mr. Beardmore, that the Thames was supplemented by 60 or 80 million gallons between Kingston and Vauxhall Bridge, and he was doubtful whether that included the Wandle or not; yet, between Kingston and Kew 400 million gallons were said to flow in during the dry weather. Mr. Mansergh had dwelt upon some of the weak points with reference to that question. Mr. Topley spoke only as a geologist. Gauging the river was an engineering question, but he did not see how it could be done except at extreme low water, and in that case, how could they tell that they were not measuring what had been stored in the gravel as the tide flowed up? He thought it was quite impossible for any observations to determine the difference between the two. As it got towards high tide, the gravel on the banks absorbed the water, and as the river fell it flowed out again. With all due deference to Mr. Harrison, and the authority which he had quoted, Mr. Topley was not at present prepared to accept the deductions from these gaugings. Surely, if there was a large amount flowing out of the gravel at low water, they ought to be able to see it. A few weeks ago he was walking along the banks at Richmond at low water, and although he had not that special object in view, he thought that if any considerable quantity of fresh water had been flowing out of the gravel, he should have noticed it. If Mr. Harrison established his point, that between Kingston and Kew there was a large increment of water from the gravel, some of it could be taken without injury to the present supply. He did not know with what object the map behind him was placed on the wall, but as Mr. Baldwin Latham was prevented from taking part in the discussion, he would refer to one interesting point not shown upon it. The arrows on the

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map showed the direction of the line of maximum inclination of the water in the Chalk, and Mr. Baldwin Latham's observations proved that the underground flow of water did not always correspond with the surface inclination. The most important difference was in the valley running from Caterham to Croydon. Instead of the underground water running straight down the valley towards Croydon, a part of it turned to the left, and went under high ground, and so came out at Carshalton. He was glad that Mr. Harrison's Paper had been brought forward. Although it had been somewhat hardly treated, there were many points in it well worthy of consideration. Mr. Topley.

Mr. Martin Peirce agreed with the opinions expressed by Mr. Mansergh and Mr. Whitaker, that the increase between Teddington and Kew was not so large as the Author had supposed. The gaugings referred to in the Paper were made by him in 1887 for Mr. Harrison. As considerable stress had been laid upon them, he would explain fully the mode in which they were taken. He chose the straightest reach with a regular bed near the point at which a gauging was desired, and at about the middle of it stretched an accurately divided and marked stranded wire line across from bank to bank at right-angles with the shore line. He then measured the depth at each mark with a graduated staff, and from these measurements calculated the cross-sectional area, which he assumed to be the average for the distance covered by the gauging. Then, equidistant on either side of this point of cross-section, he measured and staked off on both banks, a total distance of from 50 to 300 feet, and setting small floats adrift, noted the time taken by them flowing from point to point, thus finding the average speed in feet per minute. Then speed × area × 6·25 × 1,440 = quantity flowing per day. In the case of the particular gaugings in question at Kew Bridge in 1887, before he commenced gauging he fixed a stake, and noted every five minutes the fall and the rise of the tide. Similar observations had since been more completely carried out by the Conservancy, at a great number of points from Teddington down the river. On the stake he found that the water fell regularly to a certain level, and then immediately began to rise, showing that the tidal influence was never absent. If a stake was fixed nearer to Teddington, the water fell for a time, and then stood steadily at a level; it was simply the land-water running down, and until the tide came up, perhaps an hour later, it would not rise from that point. That seemed to show that there was a large amount of tidal water included in the gaugings Mr. Peirce.

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Mr. Peirce. below Kew Bridge. In sending in a report to Mr. Harrison he made a sketch of the stakes, showing the times and the rise and fall of the water, and the points at which he made his observations. The gaugings were taken at regular intervals on the different occasions, and in each case they were within $\frac{3}{4}$-inch of the lowest level to which the river fell, and within about five minutes of the turning of the tide.

Mr. Topley. Mr. TOPLEY hoped that some further information would be supplied with regard to the gaugings near Richmond, as that was one of the most important points, and ought to be fully explained.

Mr. Peirce. Mr. PEIRCE said he had no knowledge of the object of the gaugings, or he should have perhaps called Mr. Harrison's attention to that point. He knew nothing of it until he had heard the Paper read.

Mr. Harrison. Mr. J. T. HARRISON, in reply, desired in the first instance to thank the President for the kind reference to his name. There were in the Paper two proposals for providing London with water; one was to take it from the gravel-bed above Windsor, and the other from the gravel-bed which lay on the north side of a line drawn from Slough to Hampton. Sufficient could not be taken from the former source without injuriously affecting other interests, and the supply would therefore have to be supplemented. He should therefore direct his reply more especially to the proposal to draw the water from the Slough gravel-bed, which he believed would be ample. Attention had been called by Mr. Symons and Mr. Whitaker to the remarkably large increment in the volume of the Thames, as shown by the gaugings, between Kingston and Kew, and to the difficulty of separating the tidal from the land waters, and estimating the value of the increment for the London water-supply. Mr. Topley also had considered it "the crucial point of the Paper"; and rightly so, for if there was not a quantity of water entering the Thames from the gravel-beds below Kingston sufficient for the future supply of London, it would be useless to search for its source. Mr. Topley remarked that he did not see how the Thames below Teddington could be gauged "except at extreme low-water, and in that case how could they tell that they were not measuring what had been stored in the gravel as the tide flowed up." Mr. Mansergh, without committing himself to the expression of any decided opinion, proposed several pertinent questions, which it was most important to answer. It would be observed that neither Mr. Mansergh nor any one else had questioned the accuracy of the gaugings taken for the Author by Mr. Martin Peirce; these

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gaugings showed that in August, 1887, and November, 1890, after continuous dry weather in each year, the increment in the volume of water in the Thames between Kingston and Kew, at dead low water, amounted to a rate of more than 400,000,000 gallons per day. Now the first question asked by Mr. Mansergh was "If it might not be fairly assumed that all the water over and above the least quantity was tidal water?" The reply to this question would answer the two others. It might be well to mention that the gaugings taken by Mr. Peirce showed that the volume of water in the Thames at Kew was:— Mr. Harrison

					Gallons per day.
On the 10th August, 1887, at 2.40 P.M., at the rate of . .					872,780,000
,,	,,	,,	3.0	,, ,, . .	731,532,000
,, 12th	,,	,,	3.0	,, ,, . .	757,014,000
,,	,,	,,	3.20	,, ,, . .	673,951,000
,,	,,	,,	3.40	,, ,, . .	680,999,000

In each case the tide began to rise within five minutes after the last gaugings were taken, and the lowest were used in the Paper. Mr. Peirce took only one gauging in November, 1890, which was at a rate of 891,000,000 gallons per day at dead low water; if he had taken others before that period there is no doubt that the result would have been similar in character to those recorded in 1877. In reply to Mr. Mansergh's first question, it was improbable that "the water over and above the least quantity" was tidal water which had been left behind in the bed of the river, for if there had not been any land water, the bed of the river would have been left dry, as was the case in estuaries, when the tide receded, and the presence of ordinary river-water would expedite rather than retard its recession. Again, there was no large lake or pond which, having been filled with tidal water might supply the surplus through a narrow outlet towards low water. The most plausible supposition was, as had been suggested by Mr. Topley and Mr. Mansergh, that there existed above Kew a large quantity of porous gravel, into and out of which the water flowed as the tides rose and fell. With regard to this hypothesis, he would point out that the water in the land adjoining the river above Teddington weir stood at the same level as that in the river, and rose rapidly in the gravel-bed inland from the river. Under these conditions it was possible that water might enter the river above Teddington weir from the gravel, as it did above Hampton, but none could escape from the river into the gravel. The level of low water in the tidal part of the river below Teddington weir was 5·67 feet above Ordnance datum, whilst

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Mr. Harrison. the water in the land at a short distance from the river stood 15 feet, and half a mile from the banks 24 feet, above Ordnance datum. At Isleworth the low-water level was 4 feet above Ordnance datum, and the water in the land adjoining was 10 feet above Ordnance datum, and rose to 96 feet above Ordnance datum in a distance of 4 miles from the river. Again, at Kew, according to information obtained for the Author by Mr. Mansergh in 1884, the low-water level was 3 feet above Ordnance datum, and the water stood 10 feet above Ordnance datum in the gravel at a short distance from the river, and rose 5 feet higher at a distance of a mile from it. The Author was informed by Mr. Bromley and Mr. Mansergh that the level of the water in the gravel at Isleworth and Kew was not affected by the tide, excepting at Kew after a succession of very high tides, when it varied a few inches. These facts showed that at low tide there was a considerable head of water in the gravel adjoining the river, equal to at least 9 feet below Teddington weir, 6 feet opposite Isleworth and 7 feet below Kew Bridge; and under these conditions some water must of necessity escape into the river from the land adjoining; but, it might be asked, "how does it happen that the water stands thus permanently in the gravel-bed at from 6 to 9 feet above low-water level in the river?" If there were no tidal action, the water in the gravel would probably be at about the same level as that in the river, and the great height at which it actually stood indicated the influence which the tides exerted on the outflow from the land. The gravel-bed thus acted like an extensive underground reservoir or regulator, in which the water pulsated almost imperceptibly as the tide rose and fell. Now supposing the outflow to be nearly normal at dead low-water, it must necessarily be checked as the tide rose, but it could not be entirely stopped until the tidal column had balanced that in the gravel-bed. Moreover this latter column was not accurately represented by the height of the water in the land adjoining the river, for the water travelled horizontally towards the river along open pebble-beds at some depth below the surface of the ground, and its level in the land adjoining the river only indicated the resultant effect of the tidal action, passing upward through the water-carrying pebble-bed, over a large extent of water-logged gravel. Again, as the tide ebbed the discharge from the gravel must increase and attain its maximum when the tidal water had all receded, after which it must gradually decrease until it again attained its normal condition towards low-water. The observations of rise and fall of the water through a

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cycle of tides referred to by Mr. Mansergh, and kindly submitted by him to the Author, afforded some interesting and important information bearing upon this subject. The annexed diagram, *Fig. 3*, of the rise and fall of the water at Richmond between the beginning of one flood to the next (shown by the strong lines), represented the highest of the spring tides, and the lowest of the neaps in this cycle; the diagrams of the other observations at Richmond would lie within these extreme limits with very slight exceptions. These diagrams suggested the division into three periods of the time between the successive flood tides:— Mr. Harrison.

(1st.) From the beginning of the flood to high water.
(2nd.) From high water to the time when the water had fallen to 9 feet below Trinity high-water mark.
(3rd.) From that time to the commencement of the succeeding flood.

(*1st.*) *Rise of the tide at Richmond.*

	Hours.
The average time of eight spring tides was	$2\frac{7}{8}$
„ „ „ neap „	$3\frac{1}{4}$
	Ft. Ins.
The average range of eight spring tides was	10 $8\frac{1}{2}$
„ „ „ neap „	8 $9\frac{1}{4}$

(*2nd.*) *Fall of the tide to 9 feet below Trinity high-water.*

	Hours.
The average time of eight spring tides was	$6\frac{1}{2}$
„ „ „ neap „	6
	Ft. Ins.
The average range of eight spring tides was	10 0
„ „ „ neap „	8 $1\frac{1}{2}$

(*3rd.*) *Fall from 9 feet below Trinity high-water to succeeding flood.*

	Hours.
The average time of eight spring tides was	$3\frac{1}{8}$
„ „ „ neap „	$3\frac{1}{4}$
	Ft. Ins.
The average fall of eight spring tides was	0 $8\frac{3}{8}$
„ „ „ neap „	0 $7\frac{3}{8}$

The level of 9 feet below Trinity high-water mark adopted for one of the divisions was quite arbitrary; it was impossible to draw a line, and say that all the water flowing down when the river was below that level was entirely fresh water, which had never before been subjected to tidal action; but it was most improbable that there should be much, if any, tidal water flowing past Richmond during the last three hours of each tide, and there must certainly be a large quantity derived from the gravel in the tidal water

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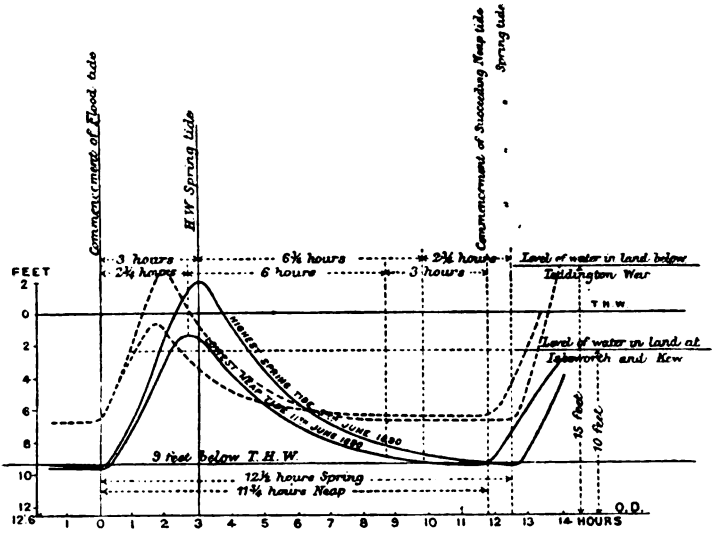
Mr. Harrison. which passed down before it had fallen to the 9-foot level. The moon was in the last quarter on the 11th of August, 1887, and consequently the gaugings on the 10th and 12th of that month were taken at the dead of the neaps, when the river would rise very little above the water in the land adjoining, and for a short time only, as shown by the diagrams—which indicated that the highest spring tide did not reach the level of the water in the land at Teddington, and only rose about 4 feet 6 inches above the water in the gravel at Isleworth and Kew, and that it did not remain longer than three hours above that level. The dotted lines on the diagram (for which the Author was indebted to Mr. More,

Fig. 3.



Engineer to the Thames Conservancy) showed the rise and fall of the tide at Teddington on the 5th and 11th of June, 1890. From these it would be observed that the period of flood tide at Teddington varied from one and three-quarter hours at neaps to two hours at springs, and the period of ebb to 6 feet 3 inches below Trinity high-water, was from four and a half hours at neaps to five hours at springs; after which the water fell a few inches and continued, for about five and three-quarter hours at neaps to about five and a half hours at springs, at nearly the same level until it flowed again. This period of low water was much longer than that at Richmond—3 miles down the river. The increment in

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the volume of the Thames between the points explained the difference in the diagrams; the time of high water was nearly the same at Teddington and Richmond. Unfortunately there were no similar observations at Kew; but the period of dead low water would probably be shorter than at Richmond, which accounted for the very short time that Mr. Peirce found between low water and the return of the flood. After giving the subject careful consideration the Author believed he was justified in his estimate that, after making large allowance for the check to the flow of water caused by tidal influence, the increment of the volume of the river between Kingston and Kew, at dead low water, justified the expectation that an ample supply for London could be obtained from the Slough gravel-bed. It must not be overlooked that a large quantity, which could not be gauged, entered the Thames below Kew. In answer to Mr. Topley's suggestion that "if there was a large amount flowing out of the gravel at low water, they ought to be able to see it," Mr. Harrison admitted that if the water issued from the banks of the river it could be seen, but not if it entered from the bed, which was sufficiently wide, deep, and long for an enormous quantity to flow in quite imperceptibly. W. Wheeler, a waterman at Richmond, gave the following evidence before the Rivers Pollution Commission in 1865: "The foul deposit is not so much in the bed of the river" (Thames at Richmond) "where it is covered at low water—it is more on the banks of the river. You may see the gravelly bottom where there is no filth upon it up stream." It was exceedingly probable that, wherever clean gravel was found in the bed of the Thames, there was an infiltration of water from the land adjoining; for the Thames naturally tended to deposit mud in its channel and to raise its bed. Mr. Mansergh said, "Surely the residents on the banks of the river at Twickenham, Richmond, and the places below, would protest in the strongest terms against this reduction of volume. They would certainly consider the consequences to be 'disastrous'"; but he seemed to have overlooked two matters of great importance; first, that only a small proportion of the water from the gravel entered the Thames above Richmond; and secondly, that if the water from this source were substituted for the existing London supply, the whole quantity now taken from the Thames by the Water Companies would pass on to Richmond, as it did before they drew their supply from above Hampton.

Mr. Harrison.

Mr. Harrison then proceeded to deal with the objections raised as to the source whence the water in the gravel-beds below Maidenhead was derived, and the alleged improbability of the Chalk

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Mr. Harrison. area yielding so large a quantity as to account for the increase of the volume of river between Kingston and Kew. He considered that there was unquestionably a very large amount of water in these gravel-beds, as shown, for instance, by the numerous ponds and lakes, which had a never-failing supply, even in the driest seasons. Dr. J. Evans and Mr. Whitaker spoke of them slightingly as "simply sheets of water formed at certain points in beds of gravel above the London Clay," but these ponds could not be fed as they were if the gravel were dry, or not constantly replenished with water. It was suggested in the Paper that the two gravel-beds were supplied respectively from the gathering ground of the Chalk westward of Maidenhead, and from the Chalk area traversed on the surface by the Colne, the Lea and their tributaries; from the former by means of infiltration to fissures running east and west, along the synclinal axis of the chalk basin, and from the latter by filtration from the Chalk into the Lower Tertiary beds—which adjoining the Chalk consisted generally of flints, pebbles, and sand—and which conveyed the water to the gravel. The process in the former case was analogous to that which occurred in the Hampshire chalk basin, and resulted in the daily discharge of 200,000,000 gallons of water near Havant at a moderate height above the sea-level; the synclinal axis of the basin ran parallel to the Portsdown Hill, which formed an anticlinal axis. The process in the latter case was similar to that recorded by Mr. Baldwin Latham to which reference would presently be made. Mr. Harrison then pointed out the very different conditions under which the chalk water was collected superficially by the Thames, and by the Colne and Lea and their tributaries. The Thames tapped the Chalk at a level of 100 feet above Ordnance datum near Maidenhead, and entered that formation considerably below the 200-feet contour near Wallingford; the result of this deep tapping being that there were extensive areas to the westward and northward of the course of the Thames entirely destitute of streams. But, tracing the northern 200-feet contour (Plate 1) which followed the course of the Thames between Wallingford and Maidenhead, eastward, it would be found that, leaving the Thames, it skirted the outcrop of the Chalk to Watford and Hertford, and ran up and down the several streams for a short distance. The Bushey Meads well, which stood steadily at 180 feet above Ordnance datum, showed that these rivers and streams did not draw the water much below that level. There was consequently a large mass of Chalk, about 570 square miles in extent, which was saturated from 180 feet and upwards

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down to the level of the water in the Slough gravel-bed, about 90 feet above Ordnance datum. Under these conditions it was very probable that the Thames above Maidenhead withdrew from the Chalk a much larger quantity of water per square mile of gathering-ground than did the Colne and the Lea; but the total quantity of water per square mile, which percolated into the two areas, was probably nearly the same; and therefore the supplementary system of the Colne and Lea, whatever that might be, must carry off a larger quantity per square mile than the supplementary system of the Thames above Windsor. The conditions under which the water was withdrawn from the Chalk formation might have been very different in the past, but they were now normal, and any interference with them by artificial means must *pro tanto* disturb them. Taking, for instance, the extreme case of a proposal to supply London by pumping from a large number of wells sunk along the 200-foot contour between Rickmansworth and Hertford; this abstraction would not prevent, though it might modify, the withdrawal of water by natural processes, as at present, into the Slough gravel, but the effect of the combined natural and artificial operations would soon be to lower the water over the Colne and Lea areas, to dry up the rivers and streams, and reduce the surface to the condition so graphically described by Dr. Evans. The proposal advocated in the Paper did not in the least interfere with the natural processes by which the water was withdrawn from the Chalk. The Colne and the Lea would flow on undisturbed. It was not proposed to pump from the Chalk, as supposed by Mr. J. C. Hawkshaw, but to collect the water which had already left it by nature's process, and to utilize it for the supply of London. As to the proportion of the rainfall which percolated into the Chalk, and might be calculated upon as a source of supply, the discussion had thrown some light on the subject, although it could not be called altogether satisfactory. Dr. Evans had come to the conclusion that "not more than 4 or 5 inches of the rainfall were available on a chalk surface as a constant source of supply," and he thought that "they must not count on more than 4 inches." Mr. Hopkinson had said that "they might have to rely for six years in succession upon $4\frac{3}{4}$ inches of percolation," or even 3 inches for a shorter period. Mr. Lucas said he "considered that the large quantity to be accounted for between the 8 or 9 inches which could be proved to flow from the springs, together with the 2 inches that might pass under the Tertiaries, and the amount indicated by Sir John Lawes' percolators, was evaporated." It was not easy to understand how this quantity

Mr. Harrison

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Mr. Harrison. could be evaporated, but it was important to notice the accurate data by which Mr. Lucas proved that 8 or 9 inches of the rainfall flowed from springs. These data were the records of the discharge from the Wendover springs; the area of gathering-ground was 4·6 square miles, and the average yield, over a period of forty-four years, was 177 cubic feet per minute, which represented a mean percolation of 9 inches of rain per annum. The maximum yield in any one year being approximately 15 inches, and the minimum 3½ inches, it appeared that the wells issued at an elevation of about 500 feet above Ordnance datum, and were situated within one mile of the outcrop of the stone bed of the Chalk formation. Now, considering the height at which these springs issued, the great depth of saturated Chalk below their gathering area, and the draught upon this Chalk, in common with that which supplied the Misburn stream and the Lower Tertiary beds to the level of 90 feet below Ordnance datum, it was obvious that the water yielded by these wells at Wendover was but a portion of the rain which percolated into the chalk surface of their gathering-ground. The information was valuable as a reliable record of the average discharge of a portion of the rain which had percolated into a well-defined Chalk area, and as a refutation of the opinions expressed by Dr. Evans and Mr. Hopkinson; but it could not be accepted as affording sufficient data for estimating the total average percolation of rain into the Chalk. The experiments recorded so carefully, over a period of twenty years, by Sir John Lawes and Dr. Gilbert, although on a small area, were extremely valuable and gave the following results: "According to the average of twenty years with rather heavy soil, free from vegetation, it might be said that the drain gauges gave about 14 inches." It will be observed that the experiments were made, not through Chalk, but through a "rather heavy soil"; but Sir John Lawes and Dr. Gilbert considered that an allowance should be made for vegetation, and they said, "Taking the average of a large area around London, partly covered with vegetation and partly bare, over a number of seasons, they thought that between 3 and 4 inches should be deducted from the 14 inches of percolation, so leaving 10 or 11 inches." It was not by any means proved that this deduction of 3 or 4 inches for vegetation should be made. Unquestionably vegetation was never so thriving as when the atmosphere was warm and humid, and that green crops grew most luxuriantly when their leaves were thoroughly wetted with dew in warm weather. As Jethro Tull said more than a century ago, "Dews are the richest present that the atmosphere gives to the

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earth." The dew was not measured by Sir John Lawes and Dr. Gilbert's percolation gauges. That the atmosphere supplied directly to the leaves a large quantity of the water which they absorbed appeared to be proved by the "grain of wheat" mentioned by Dr. J. Evans, which "could absorb if it were given to it more than the total amount of rain that fell," and by the oak tree referred to by Mr. Hopkinson, which evaporated during the whole period of its summer growth, "more than eight times the amount of rain falling upon the area covered by the tree." The following paragraph appeared in *The Globe* on the 23rd of March, 1891:— "At a meeting of the Royal Botanic Society it was reported that a poplar, which had been blown down in the gardens, had apparently derived nourishment, not from the soil, but from the decaying portions of itself." It was not improbable that this poplar derived its food, and the water which conveyed it, from the atmosphere for some time before it fell. In an interesting paper read on the 7th November, 1878, before the Linnean Society, "On the Absorption of Rain and Dew by the green parts of Plants," Professor Henslow said, "The conclusion I have arrived at is that, while there is no objection that I know of which cannot be met, there are ample reasons for believing that dew and rain are, under certain circumstances, absorbed and utilized to supplement the normal root-supply." Mr. Reeves, who had recently published a book entitled "Sap; does it Rise from the Roots?" went a step further, and contended that the leaves of trees took in the water which descended to the roots. Mr. Harrison was of opinion that neither the discharge from the Wendover wells, nor the percolation through Sir John Lawes' "rather heavy soil," gave the total average percolation into the Chalk formation, and that it was necessary to examine the discharge from the Wandle area, and some other area similarly circumstanced, if such could be found, in order to arrive at an accurate result. In reply to Mr. Santo Crimp's contention that the Author had under-estimated the drainage area of, and had over-estimated the volume of water discharged by, the Wandle, Mr. Harrison called attention to *Fig. 1*, which was based on the water contours marked on Mr. Lucas's map. According to this map the area was 53 square miles; Mr. Lucas estimated it at 54½ square miles, and as the Author, following Mr. Homersham, put it at 56 square miles, he over-estimated rather than under-estimated it. Mr. Crimp had given 26·82 million gallons per day as the average volume of water, from the chalk area, which passed Merton, according to his gaugings extending over three years, 1879 to 1881 inclusive; this quantity he reduced to

Mr. Harrison.

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Mr. Harrison. 23,000,000 gallons per day, because the rainfall was so great during that period. Accepting this as the accurate result of the gaugings, it did not appear that Mr. Crimp made any allowance for certain leakages into the Lower Tertiary beds above Merton, which were thus described by Mr. Baldwin Latham, "He started a number of gauges at different points down the river, and he ascertained that in a short distance down the Wandle at times probably not less than 10,000,000 gallons of water daily flowed out by those subterranean passages into the Woolwich and Reading beds, supplying the overflowing wells in the neighbourhood of Tooting and Wandsworth, and to a large extent supplying some of the wells under London."[1] When allowance was made for this leakage, the average daily discharge from the chalk area of the Wandle, according to Mr. Crimp's own figures, was 33,000,000 gallons per day, or 3,000,000 in excess of, instead of less, than that adopted in the Paper; 33,000,000 gallons per day from 53 square miles was equal to 15½ inches of the rainfall, or 2 inches more than was given in the Paper. Mr. Whitaker had objected, and no doubt on sufficient grounds, to the area of the Chalk above London being taken at 1,200 square miles, as measured by the maps issued by the Geological Survey Department; and stated that the Chalk was largely covered over with deposits of a more or less clayey nature, through some of which the water percolated, while it was thrown off others on to the Chalk, so that the area should be reduced by about over one-fourth, or to 900 square miles. Accepting this modification, the Colne and Lea area must be taken to be 430 square miles, instead of 570 as estimated in the Paper; and supposing it to absorb on an average 15½ inches of the annual rainfall, it would still yield 266,000,000 gallons a day, without making any allowance for the water falling on the remaining 60 square miles; this quantity, after deducting the volume carried off by the Colne and the Lea, would afford an ample supply for London. The contention of the Author was that the gaugings of the Thames at Kingston and Kew justified the suggestion made in the Paper, that a larger quantity of water entered the Thames below Teddington, from the adjoining gravel-bed, than was sufficient for the London supply; that the quantity which percolated into the gathering-grounds of the Colne and Lea with their tributaries, after making allowance for that carried off by those rivers, was abundant, and could only escape through the Lower Tertiary beds and the Slough gravel to the Thames below

[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 60.

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Teddington Weir. Also that the discharge of this surplus water was so regulated, by its collection in and its passage through the Tertiary beds, as evidenced by the constant head maintained at Bushy Mead, and by its passage through the extensive gravel-bed in the Thames Valley, that it was as nearly as possible constant, and would probably remain so, even if there were no rainfall at all for several years. The Author contended also that this water might be collected for the supply of London, without interfering in any way with the condition of the rivers Colne and Lea, or of the Thames above Teddington Weir. In reply to Mr. Grantham, Mr. Harrison remarked that proper precautions would of course be taken to avoid pollution. Professor Robinson's observations, on his report to the Local Government Board in 1884, affected only the method of collecting the water, and did not touch the question of the existence of the large volume of water in the Windsor gravel-bed, or of the source whence the water was derived. Mr. Harrison.

Correspondence.

Prof. Boyd Dawkins pointed out that it was a fallacy to assume with the Author that the whole of the water in the Chalk was available for economic purposes, because, among other reasons, it was impossible to get at a large proportion of it, which was locked up in the capillary pores of the chalk. The practically available water was in the fissures, and they were so few in the Lower Chalk that about 250 feet of its total thickness might be looked upon as unproductive. It must also be observed that the water-partings at the surface did not always mark the lines of subterranean water-partings in the rocks. In the Croydon district, for example, in which the area of catchment of surface waters was 54¼ square miles (according to Professor Dawkins's calculation), an addition was made to the subterranean waters falling into the Wandle by the drainage of the Sanderstead district on the eastern side of the water-parting at the surface. The calculation, therefore, by the Author of the amount of percolation into the Chalk within the water-shed of the Wandle, based on the gaugings of that river, without taking into account this additional area, required modification. The Author also quoted the well at Banstead as a case in which the water-level varied between the driest and the wettest seasons no more than 5 feet. If the figure 260 feet above Ordnance datum given in the Paper was accurate, the fluctuation was considerably more than that amount, since in Prof. Boyd Dawkins.

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Prof. Boyd Dawkins. February 1884 it stood at 235 feet 4 inches above Ordnance datum.

Prof. Hull. Prof. EDWARD HULL observed that the title of the Paper seemed rather misleading, for while it indicated the waters in the Chalk formation as a proposed additional source of supply to London, the Author's main object was to show that the gravel-beds of the Thames Valley, above London, were capable of yielding a large quantity, mainly derived from the Chalk by means of fissures through which the underground waters ascended. As far as he could ascertain from the abstract of the Paper, the Author left out of account the quantity of water in these gravel-beds derived from direct percolation of the rainfall, which must be very large over the areas stated, and which seemed to account for a considerable proportion of that which entered the Thames through them. It appeared to him that as these gravel-beds underlay an area thickly inhabited, and increasing in population, there might be some risk in taking a supply from such a source, owing to liability of contamination. On the other hand, he quite concurred with the Author, that the basin of the Chalk contained a large quantity of water in excess of that given off by springs or pumped by machinery. In 1878 he drew up a report on this subject, in connection with a scheme of supply from the Chalk for London, originated by Sir J. Bazalgette, Sir F. Bramwell, and Mr. E. Easton, and he came to the conclusion that after allowing 168,596,000 gallons per diem for the quantity discharged by springs, and 33,000,000 gallons as the amount then being utilized by mechanical appliances, there remained nearly 400,000,000 gallons per diem still unaccounted for, within an area of 30 miles round St. Paul's. This was not very different from the quantity (408,000,000) estimated by Mr. Homersham, while the proportion of percolating water to the rainfall, being estimated by Prof. Hull at 13·926 inches out of 26 inches, closely agreed with that arrived at by Mr. Braithwaite from observations made in the basin of the Wandle. The Author asked what became of this vast amount of unaccounted-for underground water, and suggested that it went towards saturating the gravel-beds in the valley of the Thames above London. Prof. Hull could not altogether agree with this view. Mr. Harrison appeared to think that the fault (which was not a "great" one, as he supposed) across the London basin south of the Thames must form a barrier to the water in its seaward course. But a fault of that kind, traversing both the London Clay and the Chalk, would rather act as a duct by which the subterranean waters would rise to the surface under great hydrostatic pressure.

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Prof. Hull's impression was that the surplus water of the Chalk, owing to its great hydrostatic pressure along the estuary of the Thames below London, reached the surface by means of springs along joints and fissures in the rock, both under the estuary and under the channel. This, however, was a minor consideration; on the main question of the additional supply of water for London from the Chalk formation, he felt satisfied, from a careful investigation, that sufficient might be obtained by additional pumping-stations to meet the demands of many years to come.

Professor Hull

Mr. Thomas E. M. Marsh remarked that it might be of interest to mention some particulars of an attempt to obtain water by well-sinking at the north-west fringe of the basin now under consideration, in strata immediately underlying the Chalk. The surface elevation at the point in question was considerably above that part at which it was suggested culverts might be driven to tap the subterranean waters which were supposed to exist, and were apparently not accounted for by any known surface discharges. Two shafts, 8 feet in diameter, were sunk at Swindon by the Great Western Railway Company with a view of obtaining a good water-supply for their locomotive establishment, and their other requirements at that place. They commenced at about 329 feet above Ordnance datum in strata immediately underlying the Chalk, and were carried down to 246 feet below the surface, and subsequently one of them was continued to a depth of 736 feet. Water was first met with at depths of 72 feet and 112 feet, but it was impure, containing 144 grains of saline matter per gallon. The next supply in considerable quantity was obtained at the depths of 730 and 736 feet at the base of the Oxford Clay; it contained much more saline matter, viz., 2,000 grains per gallon, and was utterly unfit for the uses intended. Pumping was continued

Mr. Marsh.

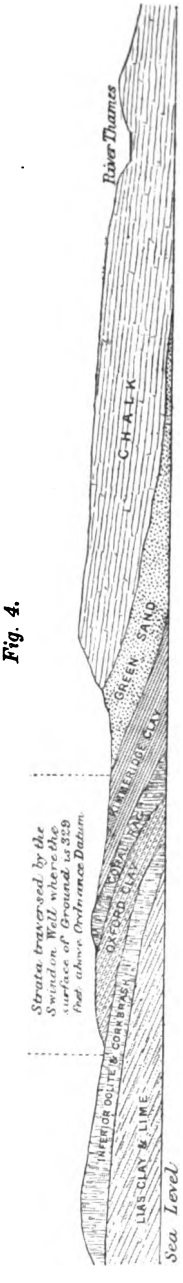

Fig. 4. Section across the Chalk Basin near Maidenhead.

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Mr. Marsh. for many months in the hope that the quality of the water might improve, but although it was kept down to 253 feet below the surface, there was no perceptible alteration for the better, and the wells had been closed since January, 1886. The water rose to and stood at a constant level of about 25 feet below the surface, or 304 feet above Ordnance datum.[1] It would be seen by *Fig. 4* (sketched from the geological map published by Professor Ramsay) representing a transverse section across the Chalk basin near Maidenhead, that the underlying sands and clays, through which the Swindon wells had been sunk, dipped to considerable depths, and formed the basin on which the Chalk reposed. The upward pressure due to the head of water maintained at Swindon would therefore be considerable, though it would be unlikely to reach or affect subterranean reservoirs, in the Chalk or gravel, such as Mr. Harrison suggested might be tapped by culverts. The facts that had been adduced in the Paper seemed to justify the hope that some practical tests might be applied to ascertain both the quantity and quality of any subterranean waters that might be advantageously utilized.

Professor Prestwich. Professor JOSEPH PRESTWICH said that since the publication of his book on "Water-bearing Strata" (1851), the progress of the Geological Survey had shown more clearly than was then possible the direction and force of the disturbances which affected the Tertiary strata and Chalk in the Thames basin. While the officers of the Survey had laid down some lines of fault in a west and east direction, they did not confirm the existence of a north and south fault crossing the Thames near Deptford. He mentioned however at the time, that though there might be a disturbance, it had more the character of a slight anticlinal line passing up the valley of the Lea than that of a true fault, and of this form of disturbance the geological maps did not take cognizance. This slight axis of elevation had, as he then said, broken the connection of the lower London tertiaries between Middlesex and Essex, and between Kent and Surrey, and consequently *none of the water in the Lower Tertiary Sands* could pass underground between those counties; but his remarks did not apply to the Chalk, as supposed by Mr. Harrison. Though the disturbance equally affected the Chalk, it would not, in the absence of any large fault, interfere materially with the underground passage of water contained in it. There could be no such resistance but what the

[1] "Account of a Well-sinking made by the Great Western Railway Company at Swindon," by Horace B. Woodward. Quarterly Journal of the Geological Society, vol. xlii. p. 287, August 1886.

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head of water could readily overcome, and the passage from west to east of the chalk water might be for all practical purposes considered unimpeded. Professor Prestwich.

He thought with the Author it was extremely probable that a certain proportion of the water, which, when the Chalk was fully saturated, escaped in springs at the lowest levels, found its way through fissures into the great bed of low-lying gravel between Windsor and Maidenhead. In fact, just before the Chalk passed under this bed of gravel a considerable spring burst out not much above the Thames level, at the foot of Taplow Hill, and no doubt on the floor of chalk, which was at yet lower levels in the valley, there were similar fissures through which the overflow water found a passage from the Chalk into the gravel. But this floor of chalk was only of limited extent, and below Windsor the bed of gravel passed on to the London Clay, so that the further supply of water from the Chalk was barred. Nevertheless, some of the water received from the Chalk above Windsor might, unless cut off by the Colne, pass further down the valley, where it became supplemented by the local rainfall, and escaped wherever the bed of gravel was cut through by the Thames; and as the river between Teddington and Kew intersected nearly the whole width of the gravel-bed, its channel there acted as a culvert to drain the sheet of water lying in that portion of the gravel which extended westward to Staines and Drayton. This, however, only affected the surface-supply, of which the measure was known, and left no reserve to draw upon.

With regard to the possible supply from the Chalk, the great question was how much of the large quantity of rainfall which fell on its surface found its way to the underground reservoirs, and what proportion of this found a free passage to a distance. As was well known, the Chalk at great depths, though water-logged, transmitted the water too slowly for any large quantity to be available. On the other hand, in the upper beds water passed freely, and the surplus escaped in surface-springs. But did it all so escape, or did any considerable proportion find its way underground to the sea and become lost? The theoretical estimates, though based on careful observations, differed widely according to whether certain conditions were admitted or not. Was it not now time to make actual underground observations so as to obtain more positive data with respect to the supply of free water which might yet be available? The number of chalk wells in London and its neighbourhood might furnish information respecting the approximate quantity now drawn

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Professor Prestwich. from the Chalk, together with more definite knowledge of the effects of pumping, and the distance to which springs and wells were affected thereby. Mr. Harrison estimated that the London wells furnished about 10,000,000 gallons daily. This was not a large amount, though the Chalk under London was riddled with wells, and yet the level of the water had been already seriously lowered. No doubt a great deal escaped from the Chalk into the river below London. The wells at Grays intercepted springs which formerly ran to waste, and the Thames from below Erith to Faversham received this overflow of innumerable springs. But in all these cases there could be no question that the water came mainly from the chalk hills of Kent and Essex, and it was doubtful whether any important contribution was received underground from the Upper Thames basin. Still the question was of so much importance that, although he believed there was little more to be obtained from the Chalk at and above London without interfering with the surface supplies, he would, in view of the great differences of opinion on the subject, rejoice to see it settled by more definite tests and experiments.

Mr. Reade. Mr. T. MELLARD READE, referring to the statement that "in round figures the Chalk, when saturated, will hold on an average 2 gallons of water in a cubic foot, or four times as much as the New Red Sandstone," pointed out that according to experiments made by him and recorded in the Proceedings of the Liverpool Geological Society, 1884, Runcorn stone (Keuper sandstone) absorbed 3·24 quarts per cubic foot and Everton stone (Bunter Sandstone) 3·08 per cubic foot. These rocks were typical of the New Red Sandstone as water-bearing strata. Taking the mean as 3·16 quarts per cubic foot and adopting the Author's 2 gallons per foot for the chalk, it would be found that two and a half times this quantity of water was required to produce saturation of the chalk instead of four times. Mr. Reade had considerable difficulty in following the geological and physiographical reasoning which led Mr. Harrison to the opinion that the gravels of Slough and Windsor were supplied from the Chalk. Scientifically the reasoning was altogether incomplete. In a case of this sort cumulative evidence was wanted; for instance, if an analysis of the water from these gravels showed that the mineral constituents were identical with those from genuine chalk-springs the contention would have great probability in its favour. Again, the estimate of the amount of water which found its way into the Chalk was based upon small experiments, useful enough in their way, but unreliable as representing the condition of a whole watershed

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composed not only of chalk but other rocks, and exposed to all conditions of tillage and vegetation. Moreover, no attempt was made to separate evaporation from total rainfall and percolation. The data on which to found the water-supply of a large city like London should in Mr. Reade's opinion be of a much fuller and more practical character. There were too many unknown quantities in the problem, and it was impossible to say, even supposing geological conditions assumed by the Author to exist, what amount of this underground water it would be possible to intercept by his scheme. Mr. Reade.

Mr. W. Sowerby thought the practical utility of the Author's project rested upon two important points. First, as to the proportion of rain that found its way into the chalk rocks and gravel beds, and secondly, the absorbing and retentive capacities of these beds. For the sake of argument, it might be assumed that the rainfall of the district was about 25 inches annually, which was equivalent to 1,600,000 tons per square mile, or 358,400,000 gallons. The first question was what proportion of this rainfall was absorbed by the ground upon which it fell; what quantity was dissipated by evaporation, and what amount flowed over the surface and through the underground streams and springs into the rivers. Sir Robert Rawlinson, K.C.B., had stated that two-thirds (that was 16½ inches) of the water which fell went back into the atmosphere and never entered the earth, or flowed down the river, so that only 8½ inches was left for absorption and surface-drainage; how he arrived at this conclusion he did not precisely state.[1] In the Paper under discussion, it would appear that the quantity which percolated into the soil was taken as 10·65 inches, while Professor Ansted estimated that 18 inches out of 26 inches rainfall could not fail to be received into the mass of the rock. Mr. Sowerby.

In calculations of this kind it might perhaps be safe to assume that one-third of the rainfall was absorbed into the ground, an equal quantity dissipated by evaporation, and the remainder flowed over the surface and near to it into the streams. When Mr. Sowerby was in charge of various works in Guzerat, India, which included the water-supply from wells, tanks, and rivers, some important questions arose relating to this subject, and as the result of an elaborate series of experiments and observations, he came to the conclusion that one-third of the rainfall flowed down the rivers. In sinking wells it was frequently found that one

[1] Minutes of Proceedings before the Committee for County Purposes of the Court of Common Council on the Question of Water Supply, Folio, 1890, p. 204.

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Mr. Sowerby. would be quite brackish, while another only a few yards distant would yield sweet water. A careful investigation showed that the brackish well got its supply from the upper strata of black soil, which contained nitrates and sodas, while the other had tapped the sweet water in the lower gravel beneath. A still more curious phenomenon was not so easily accounted for, namely, during the monsoon when the heavy rains fell, some of the deeper wells turned brackish, and as the dry weather set in became sweet again. The explanation of this was probably that the upper soil became so overcharged with water that the salts which it contained were carried into the deeper wells; but so soon as this pressure was taken off by evaporation and drainage, then the lower gravel beds began to fill them with purer water. A similar phenomenon had been observed in the wells of the Grand Junction Water Company, the water from which was frequently very hard.

It was certain that these gravel beds always when broached yielded an abundant supply of water. And as all valleys more or less resembled each other there was no doubt that a great deal could be drawn from the Chalk formations and the gravel beds of the Upper Thames Valley. But it was equally probable that the withdrawal of large quantities from these rocks and beds would have an injurious effect on the climate of the districts subjected to such a drainage of its waters. The effect would be similar to that which always followed the destruction of the forests of a country, and which might be seen in parts of Spain, India and elsewhere. Not only was the rainfall lessened, but that which fell passed rapidly over the surface without being absorbed by the soil or rocks, and the result was to produce sterile wastes. There could be no doubt that much of the water absorbed during the rains was given off again during the dry weather, as was proved by the cracks and fissures which formed after the moisture near the surface had evaporated. Although considerable quantities of water were at present obtained from the gravel beds, it was doubtful whether the proposed tunnels described in the Paper would greatly increase the yield. Sir Robert Rawlinson clearly stated this in his evidence before the City Commission.[1]

There was one important fact, however, about which there could be no doubt, namely, that any further withdrawal of water from

[1] Minutes of proceedings before the Committee for County Purposes at the Court of Common Council on the Question of Water Supply. Folio, 1890, p. 205.

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the upper reaches of the River Thames to meet the daily increasing demand, whether taken from the river itself, or from the chalk rocks and gravel beds, must have a deteriorating effect unless some subsidiary or compensatory works were introduced. The upper reaches of the Thames were kept full from the rainfall and springs, and the lower reaches within tidal influence were kept clear by the scour of the tide, and anything which interfered with or decreased those two sources must be prejudicial to the river. The question consequently arose, how could an additional supply be obtained without injury, without uncertainty and at a moderate expense? The idea suggested itself, whether any considerable portion of the heavy rainfall could be intercepted and caught in compensating- or storage-reservoirs in any part along the Valley of the Thames or its tributaries? If so, those reservoirs should be of small area, but of as great a depth as possible, as the evaporation in such cases was in inverse proportion to the square of the depths; that was, there would be as much lost by evaporation from a reservoir 1 foot deep in a day, as in a hundred days from one 10 feet deep. This he had found to be the case in India, where in deepening the village tanks, the common custom of the natives was to take out about 6 inches or a foot all over a large area, with the result that in the dry season the water rapidly evaporated; whereas by limiting the area and increasing the depth in the centre to 5 or 10 feet, the tanks remained full for a much longer period, the greater depth preventing the water from heating so rapidly and consequently retarding the evaporation. Mr. Sowerby.

But there was one thing which did not appear to have been thought of or discussed, namely, whether a considerable portion of the water required for this great city, could not be obtained at a point or points of the river where the taking up of a few hundred millions of gallons daily would have no ill effects. Assuming the population of London to be five millions, and the quantity required to be 30 gallons per head per diem, 150,000,000 gallons either was or was supposed to be delivered in a pure and filtered condition. The quantity, however, required for drinking and culinary purposes could not be more than 5 or say 10 gallons per head per day, that was to say, from one-sixth to one-third of the total, and the remainder being used for street-washing and cleansing, flushing of sewers, fire-engines and other similar purposes certainly did not require to be filtered, and might therefore be taken from any part of the river within tidal influence. Of course this would involve a double system of supply. Some forty years ago there was a project for throwing a dam or

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Mr. Sowerby. weir across the River Thames at Deptford, and thus turning the upper portion of the stream into a half tidal basin above that point. This was to have been supplemented by a broad tidal canal along the lower part of South London from Deptford to Wandsworth, and perhaps further, following the course of the Surrey Canal, and the sewerage and flood waters were to be allowed to pass into the Thames below the weir, thus keeping the upper stream free from pollution. The late Mr. John Murray, M. Inst. C.E., of Sunderland and London, took up the project, which was really only a revival of an idea of Brindley's, and Mr. Sowerby made the necessary surveys, but it was not proceeded with. Some such method of taking water from the lower reaches of the river without injury to the stream, for cleansing purposes, would solve a difficult question. Thus the quantity required for sewer-flushing, which would be much increased when the two additional sewers proposed by Sir B. Baker were built, would be met without going far from where it was wanted, and without incurring great outlay.

Mr. Harrison. Mr. J. T. HARRISON replied that Professor Boyd Dawkins was mistaken in supposing he assumed "that the whole of the water in the Chalk was available for economic purposes." The only water that could be utilized for a continuous supply for generations to come was simply that part of the rain falling upon the gathering-ground which was not evaporated or absorbed by vegetation; the large quantity of water in the Chalk was invaluable as a reservoir and regulator of the discharge, but it could not be available for economic purposes in perpetuity if more were drawn from it than that which escaped by natural processes. The map of the Wandle basin, *Fig. 1*, showed the gathering-ground on hydrogeological principles as distinct from "the area of catchment of surface-water." This area was 53 square miles, or less than Mr. Boyd Dawkins' measurement, which was 54¼ square miles, and less than that of Mr. Homersham, which was adopted in the Paper, viz., 56 square miles. There were several wells at Banstead, and the Author was aware that in some of these the level of the water varied as mentioned by Mr. Boyd Dawkins, but the fact stated in the Paper was from reliable authority, and the variation was probably due to a difference in the chalk water-bearing stratum from which the supply was drawn. In answer to the suggestion of Professor Edward Hull it was true that the Author had "left out of account the quantity of water in these gravel-beds derived from direct percolation of the rainfall," but the quantity was probably small, for the Slough gravel-bed was only about 50 square miles in extent,

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and was largely covered by deposits of brick-earth; the daily discharge over this area, supposing 15 inches of rain to enter it, would only be on the average about 30,000,000 gallons, and it was probable that this local supply would rapidly pass off and would increase the quantity which entered the Thames for a short time only. This source would certainly not materially alter Mr. Peirce's gaugings, which were taken after prolonged droughts. He thought Mr. Hull would find that the question of possible contamination by the increasing population on the gravel area was not overlooked in the Paper, and that the line for collecting the water from the gravel-bed had been selected especially with a view to avoid this source of pollution. While concurring in the suggestion that there was a large quantity unaccounted for in addition to that given off by springs and pumping, Mr. Hull had expressed himself satisfied from careful investigation that a sufficient supply of water from the chalk formation might be obtained by additional pumping stations to meet the demands of many years to come. The Author could not support this proposal, as he did not think the water could be thus withdrawn "without detriment to the Thames or to any of its tributaries." It was satisfactory to find that Professor Prestwich agreed with the Author "that it was extremely probable that a certain proportion of the water, which, when the Chalk was fully saturated, escaped in springs at the lowest levels, found its way through fissures into the great bed of low-lying gravel between Windsor and Maidenhead." The spring which he mentioned at the foot of Taplow Hill was quite in accordance with the Author's suggestion. It was also satisfactory to find that Mr. Sowerby, after bringing his experience in other countries to bear on the subject, concluded that a great quantity of water could be drawn from the chalk formation and the gravel-beds of the Thames valley. He observed that Professor Hull did not agree with him as to the disposal of the "vast amount of unaccounted-for underground water," and questioned the existence of any barrier to its progress seaward; but Professor Prestwich's observations were most satisfactory on this point, for, whatever the nature of the north and south disturbance might be, he said "that none of the water in the Lower Tertiary Sands could pass underground" between Middlesex and Essex and between Kent and Surrey, but he did not apply these remarks to the underlying Chalk. He said, however, that "it was doubtful whether any important contribution was received underground from the Upper Thames basin." This was fully in accordance with one of the principal suggestions in the Paper,

Mr. Harrison.

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Mr. Harrison. "that the progress of water seaward from the chalk formation above London was effectually barred." The view advocated in the Paper was that the water which fell on the chalk area of the Colne and the Lea percolated to the surface of saturation, which had a considerable inclination from north to south, and that it escaped from the Chalk into the Lower Tertiary beds which lay between the Chalk and the London Clay, either through fissures or by direct infiltration over a very extended surface, and that, having thus entered the Lower Tertiaries and being unable to escape by them into the adjoining similar beds in Essex, it passed by the only other available outlet, viz., the outcrop of the Lower Tertiary beds to the north-westward of Slough. One object of the Paper was to obviate Mr. Mellard Reade's objection that "the estimate of the amount of water which found its way into the Chalk was based on small experiments," by taking the River Wandle as the basis on a large scale, and the Author contended that the results were by no means unsatisfactory. Mr. Reade asked for chemical proofs. The Author could not give any analysis of the water which passed down the Slough gravel-bed, but it was probably a nearly pure chalk water. Very interesting information, however, was given by eminent chemists at the inquiry on the Lower Thames Valley Sewerage Scheme in 1880. The following was an analysis of water taken from the Thames at Molesey, from the well sunk into the gravel, belonging to the Lambeth Water Company, and from six bore-holes on the land proposed to be used for a sewage farm, lying to the south of Molesey:—

ANALYSIS OF WATER IN PARTS PER 100,000.

Places.	Lime.	Sulphuric Acid.	Hardness.		
			Temporary.	Permanent.	Total.
From the Thames at Molesey . .	12·10	2·06	16	5·7	21·7
From the Lambeth Water Company's well	12·91	2·76	15·65	8·35	24·0
Average from six bore-holes on the farm	12·77	5·55	11·5	12·9	24·8
Pure chalk water	..	..	21·0	3·7	24·7

The quantity of lime showed that all the samples contained a large proportion of chalk-water, but that the Thames water contained the least and the gravel-bed immediately adjoining it the largest amount of it. The sulphuric acid pointed to admixture of

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water derived from the Bagshot sands, which occupied 211 square miles of surface immediately to the westward; the yield in the six bore-holes had a greater proportion of water from the Bagshot sands, which contained a large quantity of iron combined with sulphuric acid, than that in the gravel-bed at the Lambeth Water Works. The Thames received a considerable quantity of water from the Bagshot formation before it reached Molesey. The temporary hardness showed the quantity of carbonate of lime, and the permanent hardness was due to sulphate of lime, magnesia, iron, baryta, &c., in the water. Mr. W. Sowerby's suggestion as to the construction of compensating reservoirs did not affect the subject treated in the Paper, and the same might be said of Mr. Thomas Marsh's interesting remarks on the wells at Swindon, which were all below the Chalk, and did not affect the supply of water from that formation. Mr. Harrison.

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LIST OF RAIN-GAUGES, EVAPORATION-GAUGES, &c.,

EXHIBITED BY THE ROYAL METEOROLOGICAL SOCIETY, IN ILLUSTRATION OF MR. HARRISON'S PAPER,

March, 1891.

Old Pattern Rain-Gauges.

12-inch Gauges.

Exhibitor.	Objects.
Negretti & Zambra . . .	Contracted Float Gauge.
	Side-Tube Rain-Gauge.

10-inch Gauges.

Kew Committee	Old Copper Rain-Gauge, constructed in 1855, and used at the Kew Observatory till June, 1890.

8-inch Gauges.

Negretti & Zambra . . .	Glaisher's earliest cylindrical form, with bevelled rim and curved pipe.
Meteorological Council .	FitzRoy's Rain-Gauge.

5-inch (and smaller) Gauges.

Negretti & Zambra . . .	Howard's Rain-Gauge. Designed by Luke Howard, F.R.S., about 1818.
L. P. Casella	Howard's Rain-Gauge, with stoneware bottle instead of glass (about 1850).
	Howard's Rain-Gauge, as modified by the late Mr. H. H. Treby of Goodamoor.
Negretti & Zambra . . .	Howard's Rain-Gauge—a first modification by Mr. G. J. Symons.
L. P. Casella	Symons' Rain-Gauge.
	5-in. Side-Tube Rain-Gauge.
G. J. Symons, F.R.S. . . .	Coffee-Pot Rain-Gauge—so called from its shape.
	Stevenson's Rain-Gauge.
	Fleming's Rain-Gauge.

Experimental Rain-Gauges.

G. J. Symons, F.R.S. . . .	From Col. Ward's original magnitude series—2-in., 4-in., and 12-in. circular gauges, and 5-in. and 10-in. square gauges. (The last is what used to be known as the Royal Engineer's Rain-Gauge.)
	From Col. Ward's original elevation series—10-ft. gauge.
	Gauge for testing the effect of porcelain as a receiving surface.

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New Pattern Rain-Gauges.

8½-inch Gauge.

Exhibitor.	Objects.
Manchester, Sheffield, & Lincolnshire Railway Company	Rain-Gauge 8½ inches in diameter, used by the Company.

8-inch Gauges.

Meteorological Council .	Meteorological Office Gauge.
Negretti & Zambra . . .	Glaisher's Gauge.

5-inch Gauges.

L. P. Casella	Symons' Snowdon Gauge.
Negretti & Zambra . . .	Symons' Galvanized Snowdon Gauge.

Mountain Rain-Gauges.

L. P. Casella	Mountain Gauge (engraving). Engineers' or Waterworks Gauge.
Negretti & Zambra . . .	Symons' Small Mountain Gauge.
L. P. Casella	Bradford Waterworks Gauge, designed by Mr. Alex. R. Binnie, M. Inst. C.E.
Negretti & Zambra . . .	Mountain Rain-Gauge, designed by Mr. T. Green of Grasmere.

Storm-Gauges.

Negretti & Zambra . . .	Symons' Storm-Gauge—*First Pattern*. Symons' Storm-Gauge—*Second Pattern*.

Registering and Recording Rain-Gauges.

Negretti & Zambra . . .	Crosley's Registering Rain-Gauge.
G. J. Symons, F.R.S. . . .	East India Company's Modified Crosley Rain-Gauge.
Yeates & Son	Yeates' Electrical Self-registering Rain-Gauge.
Kew Committee	Stutter's Registering Rain-Gauge, with twenty-four collecting jars. Beckley's Self-recording Rain-Gauge.
L. P. Casella	Casella's Self-recording Rain-Gauge.
Richard Frères	Richard's Self-recording Rain-Gauge. (Float pattern.) Richard's Self-recording Rain-Gauge. (Balance pattern.)
Professor Mascart . . .	Rain-Gauge supplied by the *Association Française pour l'Avancement de Science*. Side-tube Rain-Gauge. Hervé Mangon's Pluviomètre Totaliseur. Ordinary Gauge, with receiver holding two inches of rain, to be drawn off by the tap at its base.

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Foreign Rain-Gauges.

Exhibitor.	Objects.
Dr. G. Hellmann . . .	Hellmann's Rain- and Snow-Gauge. (First pattern-1883.)
	Hellmann's Rain- and Snow-Gauge. (Second pattern-1886, now used in the Prussian Meteorological Service.)
	Hellmann's Gauge for measuring the density of snow.
Meteorological Council .	Wild's Rain-Gauge. (Used in Russia.)
Dr. W. Marcet, F.R.S. . .	Colladon's Instrument for determining the Temperature of Hail.
Kew Committee	Nipher's Protected Snow-Gauge.

Miscellaneous Rain-Gauges.

L. P. Casella	4½-in Tropical Rain-Gauge.
	Livingston's Rain-Gauge.
Meteorological Council .	Marine Rain-Gauge.
J. Sidebottom	Snow-melting Rain-Gauge.
E. Mawley	Snow-Gauge.

Evaporation-Gauges.

L. P. Casella	Babington's Atmidometer.
Meteorological Council .	Von Lamont's Atmometer.
	Wild's Evaporimeter.
	De la Rue's Evaporimeter.
	Piche's Evaporimeter.
Richard Frères	Richard's Self-recording Evaporation-Gauge.
Cambridge Scientific Instrument Company	Evaporimeter, designed for use with growing plants in a Botanical Laboratory.
W. H. Dines, B.A. . . .	Apparatus used by the late Mr. G. Dines for measuring evaporation.
Surgeon-Major W. G. Black	Floating Rain-Gauge and Evaporating-Cup for ponds.
G. J. Symons, F.R.S. . . .	From the series of Evaporators constructed under the supervision of Mr. Rogers Field, M. Inst. C.E., and described in *British Rainfall* in 1889:—
	(1) The Fletcher Evaporator, as arranged by the late Mr. Isaac Fletcher, M.P., F.R.S.
	(2) The Watson Evaporator, as designed by Dr. Dalton, F.R.S.
	(3) Miller's Wet-sand Evaporator.
	(4) Tin Evaporator.
	(5) Tin Evaporator, with overflow.
	(6) Casella's Can.
	(7) Casella's Bottle

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Exhibitor.	Objects.
G. J. Symons, F.R.S. . . .	(8) Hook gauge, for determining depth evaporated from the large tank, 6 ft. square and 2 ft. deep, which was used as the standard wherewith the foregoing and some other forms of instrument were compared.
L. P. Casella	Casella's 8-in. Pedestal Evaporator.

Miscellaneous Instruments.

F. C. Bayard	Early Pattern of Solar Radiation Thermometer *in vacuo* with black glass bulb and certificate.
A. E. Bennett	Instrument for rendering apparent and measurable momentary oscillations of Atmospheric Pressure.
A. W. Clayden, M.A. . . .	Small Camera for Meteorological Photography. (Showing a simple method of attaching a mirror of black glass for photographing meteorological phenomena.) Larger Camera for photographing Clouds and Lightning.
Richard Frères	Statoscope. (A very sensitive atmospheric barometer.) Anemo-Cinemograph. (Indicates and registers the velocity of the wind in miles per hour, directly and without calculation.)
Kew Committee	Frame for Measuring Cloud Pictures, for determining the height and drift of clouds, designed by Lt.-Gen. R. Strachey, R.E., C.S.I., F.R.S., and Mr. G. M. Whipple.
Baldwin Latham, M. Inst. C.E.	Self-recording Apparatus for Wells, Rivers, Reservoirs, &c. (Besides its application as a tide-recording instrument, this apparatus can be used in conjunction with an overflow weir or notch for the purpose of gauging the flow of streams. It can also be applied to the fluctuation of water-level in a well, and the yield of the well, to show whether that is influenced by pumping, and it can be made to furnish data for calculating the yield of a well which has been pumped down, by automatically recording the rate at which the well refills.)
G. Meyer	Self-recording Aneroid Barometer. (Goes for a week, and marks a dot on the paper every fifteen minutes.)
R. W. Munro	Helicoid Anemometer, fitted with Dines' and Munro's arrangement for indicating at sight on a dial the velocity and pressure of the wind.

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Exhibitor.	Objects.
R. W. Munro	Robinson's Anemometer, fitted with Dines' and Munro's arrangement for indicating by a scale on a vertical glass tube the velocity and pressure of the wind.
	Helicoid Air Meter, with 6-inch helicoid fan, registering up to 100,000 feet.
Wm. Topley, F.R.S., Assoc. Inst. C.E.	Geological Model of the South-East of England.
	Photographs, Etc.
A. W. Clayden, M.A. . .	Specimens of Cloud Photographs. (Taken on ordinary Ilford plates by reflection from black mirrors.)
H. P. Curtis	New York Blizzard of March 12–14, 1888 (three views).
E. M. Eaton, Assoc. M. Inst. C.E.	Flood at Rotherham Railway Station, May 15, 1886. (Two views.)
Baldwin Latham, M. Inst. C.E.	Latham's Self-recording Rain-Gauge. (Three views.)
Professor A. Riggenbach .	Photographs of Clouds taken at the Santis Observatory, Switzerland, in 1890.
Royal Meteorological Society.	Boston Church, Lincolnshire. (Tower 273 feet high—two views.)
	Models of Hail-Stones, 7 inches in circumference, which fell near Montereau, France, on August 15th, 1888.
G. J. Symons, F.R.S. . . .	Rain-Gauge Experiments. Photographs illustrative of the Calne series.
	Rotherham Experimental Gauges. (Ten views.)
	Shot-Tower of Lead Works, Chester, 160 feet high, used as a station for determining decrease of rainfall with elevation above the ground.
	Floods, damage by—
	Two photos of Todmorden flood, July, 1870.
	Hereford Railway Station in the flood of 1875.
	Valley House, Chepstow.
	Sheet of views of Chelmsford flood, August 2nd, 1888.
	Three views of Bristol floods, March, 1889.
	Sites of Rain-Gauges in the Lake District. (Seven views.)
	Ben Nevis Observatory. (Two views.)
Professor P. Tacchini . .	Self-recording Rain-Gauge. (Used at the Ufficio Centrale di Meteorologia, Rome.)
G. B. Wetherall . . .	Flood on the Severn at Worcester, May 15, 1886. (Two views.)
Dr. C. T. Williams, M.A. .	Photograph of the Tower of the Winds, Athens.

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Maps and Diagrams.

Exhibitor.	Objects.
W. H. M. Christie, F.R.S., Astronomer Royal.	Record from Osler's Anemometer at the Royal Observatory, Greenwich, showing Rainfall for July 4–5, 1890, and corresponding Photographic Record from Thomson's Electrometer.
J. H. Gilbert, Ph.D., F.R.S.	Rothamsted Rain-Gauges.
	Rothamsted Drain (or Percolation) Gauges.
Manchester, Sheffield, & Lincolnshire Railway Company.	Map showing the sites of the Rain-Gauges on the Manchester, Sheffield, and Lincolnshire Railway.
	Statement of Rainfall in the year 1890 at the Stations of the Manchester, Sheffield, and Lincolnshire Railway.
Royal Meteorological Society.	Rainfall Atlas of Russia, prepared by Dr. Wild.
	Map of Rainfall of India, prepared under the direction of Mr. H. F. Blandford, F.R.S.
	Map of Rainfall of New South Wales in 1889, by Mr. H. C. Russell, B.A., F.R.S.
	Rainfall Chart of the United States, by Mr. C. A. Schott.
	Map of Mean Annual Rainfall of the Globe, by Professor E. Loomis.
F. Slade	Diagrams of Barometer, Thermometer, Rain, and Wind, at Barrow, 1876–9, Kenilworth, 1880–3, and Beckford, near Tewkesbury, 1884–90.
G. J. Symons, F.R.S. . . .	Map of Rainfall of part of Great Britain, prepared by the late Mr. J. Atkinson, of Carlisle, and issued March, 1840. (Believed to be the first map of any part of the British Isles showing the Rainfall.)
	Map of Rainfall over the British Isles, prepared by the late Mr. Keith Johnston.
	Map of Rainfall over the British Isles, based on the average of 1860–65, prepared by the Exhibitor for the *Sixth Report of the Rivers Pollution Commissioners.*
	Map showing the Stations from which a record of the fall of rain in the British Isles was quoted in *British Rainfall* 1889.
	Map of Rainfall of Europe, prepared by Professor Otto Krummell.
	Map of Rainfall of France, prepared by Mr. Angot.
	Map of Rainfall over the South-East of Australia and Tasmania during 1884.
	Map of Rainfall of South Australia in 1887, by Mr. C. Todd, F.R.S.
	Sheet and Album of Engravings of Self-recording Rain-Gauges.
	Waterspouts.

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10 March, 1891.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion on the Paper by Mr. John Thornhill Harrison, on "The Subterranean Water in the Chalk Formation of the Upper Thames," occupied the whole evening.

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17 March, 1891.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

Sir JOHN COODE, President, rose, after the transaction of the routine business—an act which was followed by the Council and audience—and referred to the recent decease of Sir Joseph W. Bazalgette, C.B., Past-President. Entering the Institution as a Graduate in 1838 at almost the earliest possible age, Sir Joseph Bazalgette was transferred to the class of Member in 1846; was elected a Member of Council in December 1867, a Vice-President in December 1879, and filled the office of President in 1884. His Presidential Address was mainly devoted, as his life had been given, to considerations affecting public health and welfare in all the large cities of the world, and his works—as the Engineer for many years of the Metropolitan Board of Works—will ever remain as monuments of his skill and professional ability. The President concluded with the suggestion that the members should, in solemn silence, accept the following resolution which was proposed by the Council:

"The President, Council and Members of The Institution of Civil Engineers in General Meeting assembled, have learned, with deep regret, of the death of their old and highly esteemed colleague, Sir Joseph W. Bazalgette, C.B. They desire to offer their very sincere sympathy and condolence

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with Lady Bazalgette, and the other members of the family in their bereavement."

The discussion upon the Paper by Mr. John Thornhill Harrison, on "The Subterranean Water in the Chalk Formation of the Upper Thames," was then continued and concluded.

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24 March, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2504.*)

"The Reception and Storage of Refined Petroleum in Bulk."

By WILLIAM THOMAS HENNEY CARRINGTON, M. Inst. C.E.

IN the following Paper it is intended to describe the machinery and plant required for the reception of petroleum from a tank-steamer, the storage of the oil, and its delivery from a depot in a state suitable for retail consumption, and the manner of conducting these operations.

It is assumed that the situation is such as to enable ocean steamers of from 20 to 22 feet draught of water to come alongside a pier, jetty, or quay in proximity to the storage-tanks. This being so, the construction of the depot naturally divides itself into three parts.

1. The pipes to carry the oil from the ship to the tanks.
2. The tanks to receive the oil in bulk.
3. The arrangements for drawing the oil from the tanks and delivering it in sundry ways for consumption. The Author proposes to treat more particularly of the storage of refined petroleum oil, though incidentally he may refer to the arrangements for storing petroleum spirit commonly called naphtha, crude petroleum, astatki, and lubricating-oil.

RECEPTION.

The length of the pipe-line from the ship to the receiving-tanks as a rule does not exceed 400 or 500 yards, but it may, when considered necessary, be considerably greater. A depot in the East of London was successfully supplied in this way for several years from the Regent Canal Docks, at a distance of more than a mile. The pipes are preferably of wrought-iron, their diameter varying from 6 inches to 8 inches, the smaller size being, in the Author's

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opinion, equal to all requirements, and much easier to fix and handle. The pipe-line is led from the quay, where the steamer is moored, to the tanks, and should be above ground if possible. At the quay side, where it terminates, a valve is fitted (Fig. 1, Plate 3), and between this and the ship's side or deck, where a flanged pipe is provided, a connection is made by means of a flexible hose. The oil is pumped by the ship into the receiving tanks at the rate of from 600 to 1,000 barrels per hour, the pressure on the pipes varying from 20 to 40 lbs. per square inch. The pipe-line should be so arranged that its contents, after pumping has ceased, can be promptly drawn off at one or two points, so as to enable a steamer carrying a different quality of oil to follow quickly. Cocks should be placed where air is likely to collect. At a convenient point a branch-pipe of equal diameter is led from the main delivery pipe to a "dirt-tank," having a capacity of about 20,000 gallons (Figs. 2 and 3). The first of the oil pumped from the steamer is often cloudy, and occasionally mixed with water, and it is diverted through this branch until it runs clear, before being allowed to flow into the storage-tanks. After a few days' rest in the dirt-tank the impurities settle, and the clear oil is drawn off, and either pumped into one of the receiving tanks or barrelled at once.

The arrangement of the connection between the pipe-line and the receiving tanks varies at different depots. The Author prefers to make the delivery-pipe pass in at the top and descend to the bottom, terminating in a flat-mouthed nozzle, so as to prevent the falling oil from jarring the tank. When it enters through the lower tier of the side-plates, as is sometimes the case, it is fitted with a swivel-joint, to which a length of pipe is attached, as shown in Fig. 17; it can then be used for drawing off as well, this arrangement allowing the oil to be taken from near the surface. Where the tank is on soft ground, the connection with the pipe-line must be by flexible hose, or other means must be taken to provide against settlement. Either sluice-valves or ordinary steam-valves are used; the latter are to be preferred, as they show at a glance whether they are open or shut, thus providing against a very common cause of accident at an oil depot. Joints are made with millboard and white zinc, or well-made "Molineaux's Composition." This latter may also be employed for painting the seams in tanks; it is not attacked by oil, and proves an excellent material. Shellac enters largely into its composition.

The pipe-line, when completed, is tested with hydraulic pressure

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to about 60 lbs. per square inch. It should be laid, as far as possible, in straight lengths, with T-pieces at the angles, rather than curves, so as to afford facilities for the thorough cleansing of the pipes after the delivery of a cargo of impure oil. This is done by driving through them, by means of a long rod made of ¾-inch gas-pipe, a roughly-formed piston, fitted with a leather washer. The officers of Her Majesty's Customs require a draw-off cock to be fitted in a convenient position in the line for the examination of the oil, and it is necessary from time to time to draw samples, for the purpose of noting the condition in which it is being sent into the receiving tank. A safety-valve may also be placed on the pipe-line. The flexible hose generally used are made of a number of layers of oiled canvas, strongly wired inside and out, with an outside layer of manilla cord wound round tightly. The ends of each length are fitted with gun-metal flanged connections.

Storage.

The capacity of the tanks for storing the oil varies from 3,000 barrels, or 120,000 gallons, to upwards of 20,000 barrels, or 800,000 gallons. The size suitable in any particular case will be decided to a great extent by the class of business intended to be done; thus in a depot for the reception of one uniform class of oil the tanks may vary, say, from 15,000 to 20,000 barrels each, and there may be one or two small ones of about 5,000 barrels capacity. On the other hand, a depot intended for a general business, receiving oil of various qualities, will require a number of small tanks, a few of about 15,000, and the remainder not exceeding 5,000 barrels.

Another circumstance which governs the size of the tanks is the nature of the ground on which they are to be placed. In this country the foundations vary from good shingle or rock to boggy or marshy ground. On the former, tanks of any magnitude within the limit of the powers of construction can be erected. On the latter, the size must be adapted to the supporting capabilities of the ground, the condition of which will also, to a considerable extent, affect the design, the strength of the plates, and the relation of the height to the diameter.

Foundations.—On shingly or rocky ground the foundations are provided by levelling the surface. On marshy sites many plans have been resorted to, such as :—

A. Bedding the tanks on the ground itself. This has the disadvantage of causing the bottoms to decay rapidly, as they are

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thereby made inaccessible for protection and repair, and such ground always contains much moisture.

B. Placing the tanks on a layer of concrete. The thickness of the layer requires to be considerable, in order that it may support the load without breaking up, and it adds unduly to the weight put on the foundation.

C. Placing a thick layer of brushwood on the ground, on which is laid about 1 foot 6 inches of chalk, well rammed, and on the top of this from 6 to 8 inches of clean fine ballast. This arrangement, which the Author believes he was the first to introduce, has been found to answer well, and is perhaps the cheapest way of efficiently supporting tanks on marshy ground. Foundations so made have a certain amount of elasticity, and sink to some extent with the load, but usually rise again when it is removed (Fig. 4).

D. Piles, which may have to be 40 or 50 feet in length, in order to reach the underlying hard ground, with horizontal timbers arranged suitably upon them, may be used to support the bottom of the tanks. This method is satisfactory, but costly.

E. Another type of foundation introduced by the Author, and suitable for tanks of moderate size, is shown in Fig. 5, and consists of a platform of creasoted planking laid on the ground, upon which are put a number of cross-girders formed of creasoted baulks of timber, 12 inches square, placed two or three deep, and spaced about 1 foot 6 inches apart. On the top of these are cross timbers, also creasoted, upon which the tank is built. This arrangement is costly, but has the advantage of permitting the inspection and repair of the bottom, and is specially suited for naphtha tanks. A similar plan has been followed by the Author for the support of a 5,000-barrel tank, on rocky ground, in Malta, in which case concrete walls were built, arranged, as far as possible, to avoid the seams on the bottom of the tank, and spaced about 18 inches apart (Figs. 6 and 7).

Construction of Tanks.—All large tanks are cylindrical, and as this form requires no stays it is beyond question the cheapest that can be adopted. The diameters vary from 30 feet to 80 feet, and the heights from 20 to 40 feet. These dimensions can be exceeded, especially on good foundations, but the policy of such a proceeding is to be questioned, as little or no economy in first cost is gained, and the storage of such a large quantity of oil in one receptacle increases many risks.

The Author prefers iron as the material, because he believes it to be better able to resist the action of acid, traces of which are found in the petroleum, remaining from its treatment during

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refining. On bad ground special precautions must be taken against damage to the tank, in the event of its sinking unevenly, which is not unusual, and thus becoming distorted and unsafe. Some have been ruptured from this cause, and the serious nature of the loss will be realized when it is remembered that the value of the contents of a 15,000-barrel tank may be as much as £15,000. The use of iron angle- or tee-bar stiffening rings, radial struts, and other similar devices, is not to be recommended, it being desirable to reduce as far as possible the number of rivet-holes in the outer skin; and the Author considers that to make the lower tiers of the circumferential plates stronger than those of similar tanks intended to rest on good foundations, is the best and simplest plan. The plates used for the sides measure generally about 9 feet by 5 feet 4 inches, and are double-riveted on the vertical seams. The size and pitch of riveting found satisfactory will be seen in Figs. 8 to 14. The connection between the bottom angle-iron and sides is also by double-riveting. The seams are caulked inside and outside, the edges having been previously planed to a suitable bevel. The rivets in the bottom, as well as the sides, are nobbled, the plates being punched so that the large ends of the holes come to the outside and inside respectively, thus forming a slight countersink. All the plates of the sides, and the rectangular plates of the bottom, are punched on a dividing-machine, and if this is properly done, it is not necessary that a tank should be erected at the contractor's works before delivery. The bottoms are flat, and the plates as large as possible, in order to reduce the number of seams. In this country a domed roof, having a rise of from one-twentieth to one-fifteenth of the diameter, is suitable, but in warm climates the roof should be flat and covered with about 6 inches of water, in order to keep the oil cool. In the case of the tank previously mentioned, in Malta, a continuous supply of water is delivered upon the top, and the surplus allowed to trickle over the sides, being collected at the bottom and pumped or siphoned away. The roof, which should be made as light as is consistent with strength, may be supported by trussed girders, spanning the whole diameter, or by tee-bars radiating from a central column of iron or timber, resting on the bottom. On soft ground the latter arrangement may tend to strain the roof, and in such cases the Author recommends that it should be carried by a tripod column, with its feet resting in suitable sockets attached to the lower edge of the tank sides. Manholes in the roof give access to the interior, and with the aid of windsails, afford sufficient ventilation to enable men to enter and clean the tanks a few hours after the removal of the

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oil. In some cases, manholes are fixed in the sides near the bottom; these are convenient, but must be arranged to fasten from the inside. They should be made of wrought-iron or steel. The contents are measured by soundings taken at different parts through the manholes, or other apertures provided in the roof for the purpose. They should be sufficiently numerous to enable a fair mean to be obtained in cases where the bottom is uneven. The instrument used consists of a steel tape, suitably loaded, on which is clipped a short length of ebony, placed approximately at the level of the surface. The oil rises much more slowly upon the ebony, by capillary attraction, than upon ordinary sounding-rods, so that more accurate measurements can be taken. This device is due to Mr. Boverton Redwood, F.C.S., who has done so much in connection with the importation of petroleum. The mean temperature must be measured at the same time, in order to ascertain the specific gravity of the oil. The expansion is about 1 per cent. for a change of temperature of 23° Fahrenheit; thus a depth of 25 feet of oil will be reduced about 1 inch by a fall in temperature of 8°.

In order to ascertain whether water is present at the bottom of the tank, an ingenious instrument has been invented by Messrs. Horley and Sedgley, who have made a speciality of oil measuring, and are largely engaged on this work by importers. The apparatus is shown in Fig. 23. It is lowered to the bottom, and the weighted tube then allowed to fall, thus enclosing a portion of the liquid, which can be brought to the surface and examined.

A Table is appended giving the approximate dimensions of twenty-one tanks of various sizes chiefly erected in this country. A considerable number have been constructed for the Author by Messrs. Fraser and Fraser, of Bromley-le-Bow.

Testing.—When the riveting of the bottom and the first tier has been completed, the tank being supported on blocks above the ground, water is pumped in to a depth of about 2 feet, and a careful examination made to see that the joints are perfectly watertight, after which the bottom receives two coats of hot tar or varnish and is lowered on to the foundations. When finished the tank is filled with water, and as in this condition it weighs about 25 per cent. heavier than when filled with oil, a good test of the supporting power of the foundations is obtained. Experience has shown that if a tank is made thoroughly tight for water it will hold oil equally well. Where the foundations are bad, the water is pumped in slowly and allowed to remain a fortnight or three weeks, as on marshy ground, such as that on the banks of the River Thames, the settlement will proceed very gradually for twenty or thirty days, and

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in some cases will amount to 10 or 12 inches on a well-made chalk and ballast foundation. This, however, does not represent the actual depth to which the tank has entered into the ground, but includes the sinkage of the surface, the weight producing a depression which extends over a considerable area. This is to a great extent recovered when the tank is emptied, and may be regarded as occurring each time it is filled.

An extract of a sinkage report is given, the depths being taken at the four points of the compass, the settlement at starting to pump in water being zero. The occasional reduction of the amount of sinkage is probably due to the ground becoming wet from rain or to the effect of filling adjoining tanks:—

Date.	N.	S.	E.	W.	Water Depth.
	Feet.	Feet.	Feet.	Feet.	Ft. Ins.
January 14 . .	0·56	0·60	0·57	0·65	22 7
„ 15 . .	0·57	0·61	0·58	0·66	22 7
„ 16 . .	0·57	0·63	0·60	0·67	22 7
„ 17 . .	0·57	0·64	0·62	0·68	22 7
„ 18 . .	0·60	0·65	0·64	0·71	22 7
„ 20 . .	0·64	0·67	0·64	0·70	22 7
„ 21 . .	0·65	0·67	0·64	0·74	22 7
„ 22 . .	0·00	0·70	0·64	0·76	22 7
„ 23 . .	0·69	0·71	0·69	0·78	22 7
„ 24 . .	0·69	0·71	0·70	0·77	22 7
„ 27 . .	0·71	0·72	0·71	0·78	22 7
„ 28 . .	0·72	0·75	0·73	0·82	22 7
„ 30 . .	0·71	0·80	0·78	0·89	22 7
„ 31 . .	0·74	0·78	0·78	0·86	22 7
February 1 . .	0·77	0·80	0·78	0·88	22 7
„ 3 . .	0·77	0·83	0·80	0·90	22 7
„ 5 . .	0·76	0·81	0·78	0·78	22 7
„ 6 . .	0·75	0·81	0·76	0·91	22 7
„ 7 . .	0·80	0·81	0·80	0·90	22 7
„ 8 . .	0·80	0·83	0·81	0·89	22 7
„ 10 . .	0·80	0·81	0·79	0·91	22 7
„ 11 . .	0·79	0·83	0·81	0·92	22 7
„ 12 . .	0·80	0·83	0·81	0·93	22 7
„ 13 . .	0·83	0·83	0·81	0·92	22 7
„ 14 . .	0·83	0·84	0·81	0·93	22 7
„ 15 . .	0·82	0·83	0·78	0·92	22 7
„ 17 . .	0·84	0·89	0·87	1·00	22 7
„ 18 . .	0·81	0·85	0·93	0·95	22 7
„ 19 . .	0·00	0·85	0·83	0·95	22 7
„ 20 . .	0·85	0·86	0·85	0·95	22 7
„ 21 . .	0·88	0·85	0·82	0·96	22 7

The cleansing of the tank after testing is a most important matter. It is an open question whether it should be painted inside or not. White zinc paint, which does not affect oil, put on very thin, makes a good surface. If the iron is thoroughly

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cleansed, painting may be dispensed with. The whole of the interior should be wiped down with oily cloths, a laborious process, but an absolutely necessary one if the contents are to be turned out in first-rate condition.

Delivery.

The withdrawal of the oil from the storage-tanks for the purpose of distribution is effected by a suction-pipe line running to the building where the barrelling takes place, or where the tank-wagons or barges are located. In certain depots the situation is such as to admit of the oil flowing by gravitation to the distributing department, but in most places it has to be removed by pumping. In either case a suction-pipe line is required, the diameter of which may be from 6 inches to 4 inches, and which is laid in a similar manner to that already described in the case of the delivery-pipe line, and fitted with drain-off cocks for emptying its contents. In a convenient position the pump is placed, to which the suction-pipe is connected, and by which the oil is transferred from the storage-tanks into tank-barges or wagons, or to the barrelling apparatus. When crude oil or astatki has to be dealt with a duplicate suction-pipe is necessary, or the crude-oil delivery-pipe may be used instead. This plan might be followed in the case of refined petroleum, but in practice it is often necessary to deliver it from one storage-tank whilst others are receiving oil from a steamer. By a suitable system of valves the pump can be arranged to change oil from one tank to another through the suction- and delivery-pipe lines (Figs. 15, 16), and by this means to prepare large tanks for the reception of a shipment by transferring any small quantities that may be left in them to one of the small tanks. Where these do not exceed 25 feet in height the use of temporary suction-pipes passed through the manhole to the required depth is often convenient. Oil can thus be drawn from any desired level, and the complication of the internal swivel-joint (Fig. 17), which is inaccessible, is avoided.

The pumping engines usually employed are of the Worthington type, which seems to be well suited for the work, though somewhat extravagant in the consumption of fuel. The quantity of oil required to be dealt with per day in most depots does not exceed 1,500 or 2,000 barrels. When tank-wagons or barges are employed, the rate of delivery is often as much as 20,000 gallons per hour, each wagon containing about 60 barrels and an average tank-barge 600 barrels. The oil is raised into a small tank placed near the barrelling-house,

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at an altitude of 8 or 10 feet, and from this is run into the barrels. The apparatus consists of a pipe placed about 30 inches above the ground and fitted with branches 7 feet apart (see Fig. 18), from which are led flexible hose terminating in automatic cocks. The barrels are rolled from the shed into the proper position, the attendant puts the cocks in the bungholes, and as filling proceeds places an empty barrel alongside. As soon as sufficient oil has run into the first, space being left for expansion, the automatic cock shuts off the supply, and the attendant lifts the cock from the full barrel and enters it into the empty one, drives a bung into the barrel just filled, pushes it forward, and replaces it with another. The weight of these cocks is balanced, so as to diminish as much as possible the labour of using them. A well-arranged apparatus enables one man to fill upwards of fifty barrels per hour. There are several types of automatic cocks; perhaps the most efficient is that made by the Standard Oil Company in America. It acts by a float in the nozzle operating a catch, which releases a valve in the neck of the cock (Figs. 19 to 21). The bungs or shives are dipped into hot glue before being driven in, and after filling the barrels pass forward for delivery, the weight being recorded on the delivery-note. Before the barrels are in a fit state for holding the oil a great deal of work has to be done to them. When the empties are received at the depot from the collectors, they are sorted and closely examined, and those in good condition are placed ready for glueing. Those requiring repairs are passed into the coopering department, where they are made sound, and sent forward to be coated inside with a thin skin of glue for the purpose of making them perfectly oil-tight. A weak mixture of glue and water is kept hot in a steam boiling-pan (Fig. 22), and into each barrel about a quart of it is poured, a bung kept for the purpose driven in promptly, and the barrel turned about on its end by the attendant in such a manner that the glue passes over the whole of the internal surface. This is an operation requiring experience, but a skilled man can do it most efficiently. Having given it two or three turns according to his custom, he strikes the barrel near the bung-hole, causing the bung to jump out with a small delivery of steam. It is then moved forward and allowed to lie with the bung-hole downwards over a trough, into which the surplus glue drains and from which it is pumped back into the boiling-pan for re-use. After draining, the barrels are moved forward into the drying-room, where they are allowed to remain until they are dry, and are then painted blue with white ends. The quality of paint used is extremely poor, a quantity of naphtha

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being mixed with it in order to make it dry quickly. It is laid on by boys and men with large brushes, and forms an employment at which they become very expert. In some cases, the painting is done by simple immersion, but this process is more wasteful. Recently a brush worked by steam power is said to have been used with success. Before the barrels are passed to the filling apparatus they are weighed and the tare marked on them; their ends are also stencilled with the brand of the oil.

The use of barrels as a receptacle during distribution was almost universal up to the end of 1889, but since then attempts have been made, notably in the case of American oil, to distribute in bulk by means of tank-carts containing from 500 to 600 gallons, a system which has met with considerable success. Under the present arrangement it is sold by measurement and not by the weight delivered, and the quantity is therefore affected by the temperature. Large numbers of barrels are now in use, and they form a strong, easily-handled, and undamageable package, and are of a form convenient for use on the inclined runs by which they are moved from point to point in a depot. Their value varies according to the demand from 3*s.* to 4*s.* 6*d.* They cost new in the United States about 6*s.* each.

The Paper is accompanied by two sheets of illustrations, from which Plate 3 has been prepared.

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APPENDIX.—Sizes and Dimensions of Various Petroleum-Tanks.

Contents.		Dimensions.				Thickness of the plates.									Remarks.
Barrels.	Gallons.	Diameter.		Height.		Bottom.	Top.	1st Tier.	2nd Tier.	3rd Tier.	4th Tier.	5th Tier.	6th Tier.	7th Tier.	8th Tier.	
		Feet	Ins.	Feet	Ins.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
1,500	60,000	30	0	13	9	⅜	⅛B	¼	7/32	5/16B	..	..	..	..	..	On a yielding foundation.
3,000	120,000	40	0	15	6	⅜	⅛B	⅜F	9/16	¼	..	..	..	..	..	,, ,, ,,
4,000	160,000	40	0	20	8	⅜	⅛B	½	⅜F	5/16	¼	..	..	..	..	,, ,, ,,
4,900	196,000	40	0	26	0	¼	⅛	⅜	⅜	9/16	9/16	¼	¼	..	..	On a firm foundation.
4,900	196,000	40	0	26	0	¼F	⅛B	⅜	9/16	¼F	¼	¼	¼B	..	..	,, ,, ,,
5,000	200,000	40	6	25	3	½	⅛B	⅝	⅜	9/16	5/16	¼	..	..	..	On a yielding foundation.
5,100	204,000	45	0	20	8	⅜	⅛B	½	13/32	9/16	¼	..	..	..	..	,, ,, ,,
5,700	228,000	40	0	29	9	⅜	¼	⅜	⅜	5/16	9/32	¼	¼	..	..	Flat top. Rock foundation.
6,860	274,400	40	0	36	6	⅜	⅛	7/16	7/16	⅜	5/16F	5/16F	¼F	¼	¼	Unyielding foundation.
7,050	282,000	47	0	26	0	5/16	⅛B	⅜	5/16F	5/16	¼F	¼	¼	..	..	
9,050	362,000	50	0	30	0	9/32	⅛F	11/32	5/16B	9/32	¼F	¼B	7/32	7/32B	7/32B	Flat top.
10,000	400,000	52	0	30	0	5/16F	⅛B	⅜	5/16F	5/16B	¼F	¼	¼B	..	..	On a firm foundation.
13,030	521,250	60	0	30	0	5/16B	9/32	⅜F	11/32	5/16B	9/32	¼	¼B	7/32	7/32	Flat top.
13,700	548,800	60	0	32	4	⅜	3/16	½	½	7/16	5/16	5/16	¼	¼	..	
15,000	600,000	70	0	25	0	½	⅛	¼F	7/16F	⅜	5/16F	¼F	..	..	..	
15,150	606,000	70	0	25	3	½	⅛F	¾	⅝	⅜	9/16	¼	..	..	..	On a yielding foundation.
15,250	610,000	64	0	30	4	⅜	⅛	7/16	7/16	⅜	⅜	5/16	¼F	¼F	..	
17,580	703,200	70	0	30	0	5/16B	¼F	⅜F	11/32	5/16B	9/32	¼F	¼B	7/32	7/32	Flat top.
17,800	712,600	67	6	32	4	⅜	3/16	9/16	½	7/16	⅜	5/16	¼	¼	..	
21,000	840,000	72	0	33	0	¼	⅛	⅜	⅜	9/16	9/16	¼	¼	9/16	9/16	
21,500	860,000	74	0	32	4	⅜	3/16	9/16	9/16	½	7/16	⅜	5/16	¼	..	

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Discussion.

Mr. CARRINGTON said he had included in his Paper simply the description of a depot for receiving petroleum from a tank-steamer and storing it, and of the arrangements for delivering it to the retail dealers. With respect to the carriage of oil in tank-steamers he had said nothing; the subject, however, had been treated by a naval architect in a Paper read before another Society. Without going into the question of accidents that had taken place in the steamers, he might remark that they had occurred almost entirely through carelessness, and not through anything in the construction of the ships. In a case which lately came before his notice, a steamer which had been used for the carriage of petroleum in bulk was taken into dock for sundry repairs to her bulkhead, &c., which had suffered in a heavy storm in the Atlantic. The contractors in executing the alterations cut a rivet out of one of the masts, when a large quantity of oil gushed out. Luckily there was no accident; but there were all the elements of one, for they had the forges, &c., in the tank. He did not think there was much improvement to be made in tank-steamers, except perhaps in keeping them more tight, so that no water might be mixed with the oil, as was now often the case. He had very little to add to the Paper. The arrangements described were such, he believed, as were generally adopted in petroleum stores in this country. Most of the large ones were in isolated situations, where very little watch could be kept over the tanks, and therefore every effort was made to prevent them being tampered with. The measurement of the oil might well be done, and perhaps with greater accuracy, with water-gauges fixed to the tanks; but these would constitute an element of weakness. The breaking off of a cock might cause the loss of many hundred, if not thousand, pounds' worth of oil during a night. All the fittings were designed with a view of preventing any possible loss of oil through malicious damage, which they had to provide against in most of the depots of this country. Unfortunately, in the Thames district, nearly all the tanks had to be placed on extremely bad ground. The chalk and ballast foundation which he had introduced had answered very well. Some tanks which were placed on the ordinary concrete foundation sank as much as 3 feet into the ground, and had to be removed, owing to the great

Mr. Carrington.

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Mr. Carrington. danger of their sinking further. Respecting the carriage of oil from a depot for distribution, tank-cars on the railways had been introduced by one large importing company into this country, and they would be, no doubt, still more generally employed; but at present, with this exception, the work was done almost entirely by tank-barges or barrels. There was little difficulty in arranging for the carriage of oil in tanks over the railways at present, but owing to the situation of most of the depots, they had to be smaller than was convenient. Tank-wagons for distributing petroleum through the streets in London had been used satisfactorily, and had given good results; but it should always be remembered that in such cases it was sold by measurement, and therefore variations of temperature must affect the quantity received by the purchaser.

Mr. Redwood. Mr. Boverton Redwood thought the subject which had been introduced in the Author's interesting and instructive Paper was worthy of the attention of the Institution, not only in respect of the enormous development of the use of mineral oils for illuminating purposes, but also in view of the probability that these hydrocarbons would in the future be employed to a still greater extent as liquid fuels and as a source of illuminating gas. It was worthy of note that the first attempts made in this country to introduce the storage of petroleum in bulk were not connected with the system of bulk transportation, but arose from a desire on the part of certain wharfingers to minimize the leakage which was found to attend the use of barrels. It was to Mr. Ingall that the trade was indebted for the first installation of the kind in England. As long ago as 1868–9 Mr. Ingall fitted up at Mellish's wharf in London some comparatively small tanks for the storage of Scotch shale oil, and a few years later he constructed a number of rectangular iron tanks at Palmer's Wharf, Bethnal Green, for the reception of the American oil which was then being imported in considerable quantities. With regard to the development of the tank system of transport, probably no one more clearly recognized the advantages afforded by it than the late Mr. Charles Marvin, who, in his various writings connected with the subject of Russian petroleum, strongly advocated transportation in bulk. In Russia it was a matter of necessity, in consequence of the scarcity of suitable timber, but Mr. Marvin realized that, even in cases where barrels could readily be obtained at a small cost, considerable advantages resulted from the adoption of a system of bulk transportation and storage. Mr. Redwood could not personally lay claim to the prescience

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Mr. Redwood.

exhibited by Mr. Marvin, but he might say that on his return from a visit to the Russian oil-fields in 1875, at which time no American oil had been transported in bulk to this country or to the European continent, he ventured to express the belief that a system which had been found successful in the transport of petroleum on the Caspian Sea would in due course be used to carry it across the Atlantic. In the following year 1876 two sailing vessels were fitted for bringing petroleum from America—the "Crusader," which he had the opportunity of seeing in New York and again on her arrival in England, and the "Andromeda"—and it was an illustration of the apprehensions of those who made the early experiments, that in both cases a large number of comparatively small tanks were employed. In the "Crusader," which was quite a small vessel, there were no less than forty-five cylindrical tanks, and the average capacity of them was only about one hundred and twenty-five barrels. There were some grounds for apprehension, because there had been earlier attempts at the ocean transport of petroleum in bulk which had been attended by the loss of the vessels, the oscillation of the oil during rough weather having been insufficiently guarded against. Those two ships, however, to which he had alluded, made several voyages with great success, and soon after there commenced the construction of the large fleet of petroleum tank-steamers, built by Sir W. G. Armstrong, Mitchell & Co., and other firms, which were now regularly running between the United States and Russia and the various consuming countries. The important principle which it had been found necessary to have carefully in view in the construction and use of those vessels was that of keeping the main storage-tanks full of oil. Expansion trunks were provided for this purpose. There was one point to which it might be well to direct the attention of the meeting. It would probably be admitted by Mr. Carrington that, at any rate with regard to London, the question whether a tank-steamer should discharge her cargo directly into the storage-tanks through a pipe, as indicated in his Paper, or into bulk barges in which it might be conveyed to storage-centres more conveniently situated for distribution, had not been definitely settled. It might be said that there were two distinct schools of thought on the subject. There were those who considered it best that the tank-steamer should proceed to some wharf on a river where she could lie alongside the quay and discharge the oil directly into the storage-tanks. In that case it was necessary that much of the petroleum, when required for consumption, should be conveyed to a considerable distance from

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Mr. Redwood. the wharves, either in bulk barges, or in other ways. On the other hand, there were some who said it was better that the cargo, on arriving, should be placed as quickly as possible in convenient centres for distribution. That, as he had indicated, also necessitated the employment of bulk barges, into which the cargo was pumped at the time of the arrival of the steamer. Those barges proceeded by canal to wharves which lay as a rule in somewhat densely populated neighbourhoods, where the consumption of petroleum was large. On the purely engineering aspect of the Paper he had very little to say, and should feel hesitation in making any statement to that assembly; but he might point out that in addition to the jarring of the tank, which the Author had avoided by the use of a discharge pipe of a certain form, there was another effect which it was highly desirable to prevent. Petroleum was readily converted into spray, and from the point of view of economy it was important that it should be discharged in such a manner as to bring about that condition to as small an extent as possible. In certain circumstances there was an advantage in having a layer of water at the bottom of the tank. That he found was a practice commonly observed in Russia, and it had to some extent been followed out in this country. It obviously facilitated the accurate measurement of the depth of oil in the tank, giving a perfectly level bottom to measure from; but he was bound to say from experience that he could not in all cases recommend its adoption, especially in the case of certain descriptions of petroleum which took up water more readily than the Russian oil. With reference to the form of the top of the tanks, he could only, as an inspector of petroleum, appeal to Mr. Carrington to consider in his designs the convenience of those who had to measure the oil. In most cases they were erected in exposed positions; and with a top of high curvature, especially in certain states of the weather, the conduct of the necessary operations, which had to be performed through man-holes in the roof, became not only difficult, but even dangerous. The water-top which Mr. Carrington had alluded to had been adopted in certain cases in this country, and it was apparently considered to be a desirable feature. It was a common method of construction in Russia, but in his opinion was not demanded by the climatic conditions which ordinarily prevailed in England. Mr. Carrington had spoken of the use of gauges for measuring the height of the oil in the tank as being a method which under certain altered conditions of observation it might be desirable to adopt; but he might point out that a considerable number of tanks in this

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country were already fitted with them. He might also say from practical experience that they could not measure the depth of oil as accurately with such gauges as by dipping through the man-holes in the way described. The tanks were usually out of plumb, and unless they were fitted with a considerable number of gauges, it was not easy to obtain results as satisfactory as those given by the old method. Tank-storage had undoubtedly a great advantage over barrel-storage in case of fire. A notable example of the comparative safety of the system occurred during the fire at Dudgeon's Wharf in 1886, when several of the tanks became highly heated, and in certain instances the contents were ignited, but in no case was any important amount of oil destroyed, nor was there any serious danger to the surrounding property. A still more marked illustration of the same thing occurred in the fire at Antwerp in 1889. He had occasion to go there immediately after for the purpose of making a report on the occurrence. It would be remembered that it originated from an explosion in a cartridge factory. There was a very large tank, nearly full of petroleum, which was to some extent injured by the explosion, but not so as to cause it to leak much. The explosion also ignited a store containing a quantity of mineral oil in barrels. The fire burnt furiously for something like two days, and the direction of the wind was such as to carry the flames towards the petroleum tank to which he had alluded. At a distance of only ten feet stood a telegraph post which was practically destroyed by the flames, and the tank itself on that side was considerably scorched, yet the contents remained unignited, and the oil was found after the conflagration was extinguished to be in a perfectly merchantable condition. There had been other illustrations to which he might allude, but these were probably sufficient to indicate that there was as a matter of fact a great advantage in tank-storage from the point of view of safety in case of fire. There was one description of tank about which he would say a few words, because he thought that in the future the importation of petroleum for use as fuel would be greatly increased, and it might be possible to carry out some similar plan in this country. In the Canadian oil-fields it was the invariable practice to store petroleum in large tanks excavated in a particularly retentive description of clay. They were often as much as 30 feet in diameter by 60 feet in depth, and held from 5,000 to 8,000 barrels of oil. The alluvial soil, of which there was about 18 or 20 feet above the clay, was kerbed with wood and thoroughly puddled with clay. On the completion of the excavation the entire vertical

Mr. Redwood.

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Mr. Redwood. surface was then lined with rings of pine wood, the upper part down to the solid clay having a double layer. The bottom was not lined, and the roof was of wood covered with clay. The cost of such a tank was about 22 cents (11*d.*) per barrel, or $1,760 (£363) for an 8,000-barrel tank, and the time occupied in making one of that size was about six weeks. With regard to the question of distribution, he thought it right to point out that the barrel, although in some respects an undesirable package, possessed great advantages, and probably would not be superseded in the immediate future. He had already said that the primary object of the erection of tank-stores in this country was the minimizing of leakage. It must be freely admitted that barrels were not ideal packages in which to keep mineral oils for any considerable length of time. If they were piled to any great height the lower tiers rapidly became leaky under the pressure, and they were liable, especially in certain states of the weather, to become dry, and then the contents were apt to be lost. Nevertheless, they presented great advantages, and he thought that, notwithstanding the growing introduction of the bulk system of transportation, it would always be found that in certain cases a barrel or some equivalent package would have to be used. In that connection he might mention that attempts were being made to introduce other materials for the purpose. A short time ago he had occasion to examine a steel barrel, and a barrel made of paper, both of which appeared to possess useful properties. Practically the question of the employment of tank-wagons as a convenient system of distribution had long since been solved. When he was last in the United States, he found that the use of tank railway- and road-wagons had extended throughout the whole of the continent, and in point of fact from all the important centres and in all the large towns petroleum was being distributed in this way. He did not consider that any such system could entirely supersede the use of the barrel. He would remark in conclusion that although storage in tanks undoubtedly presented great advantages in case of fire, yet the readiness with which petroleum contained in barrels ignited was greatly exaggerated. In company with an officer of the Metropolitan Board of Works he had visited an oilman's premises which had been destroyed by fire, and he had seen barrels so badly charred that in the upper portions he could push his finger through the staves, yet still they retained their contents unburnt. He was of opinion that petroleum in barrels might be looked upon as much less inflammable in a warehouse than was generally assumed.

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Mr. S. H. TERRY said that until eighteen months ago he had had no experience in connection with petroleum; but last year he was connected with the construction of five large tanks of an aggregate capacity of more than 4,000,000 gallons (about 15,000 tons), two abroad, and three in England, viz., one at Purfleet, and two for the Mersey Docks Board. He had the permission of Mr. Lyster, the Engineer of the Board, to describe these last. The weight of iron used was about 95 tons in the smaller tanks, and 115 tons in the larger, and the cost of the storage provided was at the rate of about £3 per 1,000 gallons. They were, in many respects, similar to those of the best kind mentioned by Mr. Carrington, but they differed in one or two points, especially in the construction of the roof. He might mention that he was the managing partner at the time, and had sole charge of the construction. One was 67 feet 6 inches in diameter, and 32 feet high, and the other was of the same height, but 60 feet in diameter. The capacity of the larger one was 700,000 gallons, and of the smaller 560,000 gallons. They were constructed entirely of iron, Staffordshire T. K. quality. The test to which the Board put it was very severe, as they were determined that it should be second to none in quality. The De Bergue pneumatic riveter was employed during the construction, and was found to be an excellent machine, tolerably light and convenient to move about, and only requiring a small air reservoir instead of a heavy accumulator, neither the air-pump, and steam-engine and boiler, nor the reservoir, having any other foundation than a few planks. For fixed work the hydraulic riveter was excellent; but for working at some distance from the centre the pneumatic machine appeared to have the advantage. The thickness of the plates decreased in the way the Author had described from $\frac{5}{8}$ inch at the bottom to $\frac{1}{4}$ inch at the top. All the edges of the plates were planed, single riveting being used for the horizontal seams and double riveting for the vertical ones. The sides were continued about 6 inches above the level of the top, which was flat, so that it might carry water for the purpose of keeping the tank cool in hot weather. The roof had deep radial girders extending from the side to a framed ring in the centre, with rafters and purlins joining the girders at suitable intervals. They dispensed with any central support for the roof, and in that respect differed from the tanks described in the Paper. He need not point out that there was a great advantage in having no inside obstructions: it enabled the tank to be more easily cleaned, and there were fewer places where dirt and debris could collect. It was better

Mr. Terry

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Mr. Terry. to avoid timber props in a tank with such an inflammable material as petroleum. He had seen cases in which the roof was carried by wooden framing; but it appeared to him that this must become saturated, and after the tanks had been emptied for days or even weeks the timber would give off petroleum vapour, adding to the danger in case of fire, and in any case wasting the petroleum. By making the roof entirely self-supporting they could dispense with timber while the tank was in use. The Mersey Docks Board depot for petroleum, known as the Park Hill estate, was situated on that part of the river called the Herculaneum Dock, at the south-east end of Liverpool, and the soil was peculiarly suitable for building tanks, being all easily worked sandstone, so that they had none of the trouble due to sinking of the foundations. The rock was terraced out level, and on it there were built massive concrete walls. Round each tank was a separate wall of great thickness, and of such a height that if anything should happen to the tank the walls would contain the whole of the liquid that would flow out. There was thus no chance of any oil getting into the Mersey. A complete system of pipe-lines was laid from the Herculaneum Dock below, where the vessels could lie, and the oil was pumped from them and delivered into the tanks immediately on arrival. He had brought with him three drawings of the petroleum depot. He did not like to differ from so high an authority as Mr. Redwood, but there were times in this country—for example, during the months of July and August—when the days were exceedingly hot, and it was natural that the Mersey Docks Board should wish to be on the safe side; and he thought they were justified in going to a slight extra cost for putting water on the top of the tanks. It was, however, a question whether the ledge provided was sufficient, because, being in rather an exposed situation, it was possible that the wind would strip much of the water off the tank. The depth of water was 4 inches, but the edge of the tank was raised 6 inches above the roof, so that there was a margin of 2 inches, and the ground being very solid, there was no fear of uneven settlement. The tops of the tanks were perfectly level. With regard to the method of fastening the rafters to the top ring of plates, he thought it was probable that in future every alternate plate from which the rafters sprang would be made $\frac{3}{8}$ inch thick instead of $\frac{1}{4}$ inch, which was hardly enough to support a rafter reaching half way across a 67-foot 6-inch tank. On the whole they were exceedingly satisfactory, and had proved to be absolutely tight, which was a great point. His late firm constructed two of them; five had been

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Mr. Terry.

already built, of which the Widnes Foundry Company made three, one slightly larger and one much smaller than those described. They were riveted entirely by hand, and the time occupied was about the same. With regard to machine-riveting, he thought, from his experience, that its advantage in an exposed situation, where the wind blew strongly and they were liable to get a great deal of wet and cold, was very great, and petroleum tanks were generally in exposed places. That circumstance was certainly in favour of machine-riveting, because they could make more rapid progress during a given number of working hours. If there had not been a certain amount of feeling promoted by the riveters that they should not get through more work than the other firm in spite of the advantage given by the machine, he believed they would have been considerably ahead, although they had less than half the number of men employed by the other company. It was well known, however, that there was not too great eagerness on the part of men to adopt machinery. With reference to the gauges, the Engineer of the Dock Board made careful investigations as to the best means of measuring the volume of oil contained in the tanks at a given time. It had been proposed to have a wheel with a float, and a fine piano-wire coming out through the top of the tanks and going over a wheel outside, in order to avoid the hole in the side which water-gauges necessitated; but that idea was abandoned, as it was thought that the friction of the wire might affect the indications, and the following arrangement, suggested by his firm, was adopted. A hole was made in the bottom of the tank, and a vertical steel pipe, 2 inches in diameter, was connected with it, with water-gauges fixed at intervals. This pipe was controlled by an automatic valve at the bottom, and also a screw valve, so that they could in a moment disconnect the whole of the water-gauges, or in the event of a glass tube breaking, the automatic valve would close. That was an advantage over the system of screwing water-gauges direct into the plates of the tank. In the first place, the connections could be shut at night by merely closing the valve, and they need only be used when it was desired to ascertain the height of the liquid in them. For lifting the plates into position and for carrying the pneumatic riveter (which weighed about 11 cwt., having a 5-foot gap), he designed and constructed a light steel tubular crane, the jib of which was composed of two double-tapered tubes made of steel plate $\frac{1}{8}$ inch thick. These tubes were riveted up in three lengths each with flanges at the joints. They sprang from a base about 4 feet 6 inches apart,

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Mr. Terry. and joined at the top by entering two sockets in a twin casting carrying the pulley. Their lower ends were fixed in two separate eyed sockets, turning on pins; between the flanges a kite-shaped wrought-iron plate stiffened with iron tee-bar about 6 feet long was inserted, and the flanges bolted up together. Stay-rods with tightening screws extended from the jib-head over cast-iron eyes on the kite-shaped pieces to a distance-piece connecting the two sockets at the lower end of the jib, which was thus made exceedingly rigid, so that practically no vibration occurred when the riveter was working. Before inserting the ends of the steel pipe into the cast-iron sockets, tapering pieces of pitch-pine were forced into them, so that when the pipes were driven into the sockets they should not be crushed inwards. The jib sockets turned on pins passing through eyes in a casting bolted on to a frame consisting of 16-feet lengths of H-bar resting on a cast-iron top and bottom turntable, with rollers to carry the weight, and a central pin to hold the two tables together, the whole being supported by a wooden frame resting on the bottom of the tank exactly in the centre. At the tail end of the H-bar frame a plate-iron box was made for counterweights, beneath which one wheel, resting on the plates of the tank, was fitted to steady the whole. As far back as possible, viz., some 16 feet from the jib-foot, a cast-iron barrel for steel rope and worm-gear was bolted. This barrel was in three sections, one for hoisting the load or riveter, the other two outer ones for coiling the guy-ropes which stayed the jib. The total length of the jib was 64 feet, and it was capable of lifting the riveter 40 feet high at a radius of 35 feet, and was tested with a 30-cwt. load. It was easily manipulated by one man, who hoisted, lowered, derricked, or slued, as occasion required. The men working the riveter, and engaged in caulking, stood on a platform carried by grooved wheels running round the edges of the plates of the tank, and kept away from the sides by rollers on vertical shafts. By this means and by the crane already described the tanks were built entirely without scaffolding. In future he intended to use as a counterweight for the crane a cylindrical air-reservoir. The rivets were heated on the ground-level in stoves, burning crude black oil, and blown direct from the riveter air-supply by means of ½-inch branch-pipes. It would be possible, however, to devise a better system of heating rivets on the stages; and this, with the introduction of a pneumatic caulking tool, would probably have shortened the time of building some 20 per cent. The following figures with regard to petroleum might not be out of place:—The weight of 1 gallon = 8 lbs.; one

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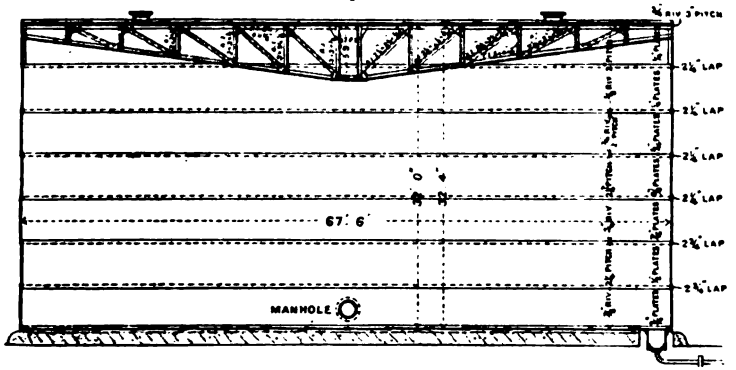
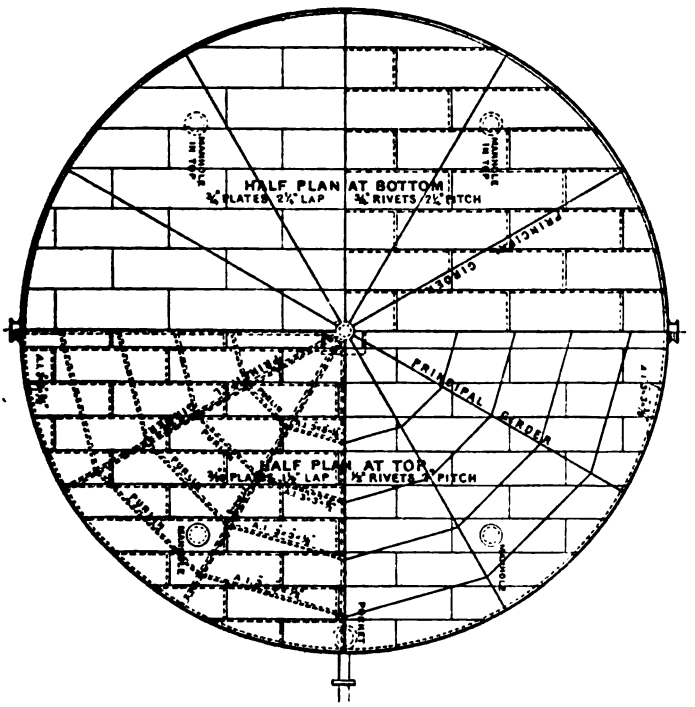
Mr. Terry.

Figs. 1.





Scale $\frac{1}{16}$ inch = 1 foot.

PARK HILL PETROLEUM TANK, LIVERPOOL.

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Mr. Terry. barrel = 40 gallons, or 320 lbs.; 7 barrels = 280 gallons = 1 ton. *Figs. 1* showed the construction of the tank at the Park Hill estate of the Mersey Docks Board as designed by their Engineer, Mr. Lyster, M. Inst. C.E., whom Mr. Terry had to thank for permitting him to use the drawings. In conclusion he would add that the employment of electric light seemed specially desirable for these depots as a precaution against fire, and to render them safe from malicious injury at night, and also as facilitating the night-pumping or transfer of petroleum either in bulk or in barrels. It was desirable that lightning conductors should be fixed to all tanks and buildings where petroleum was stored or handled.

Mr. De Michele. Mr. V. De Michele asked if the tanks were open to the atmosphere or not; and if they were, whether there was any record of the waste.

Mr. Webster. Mr. J. J. Webster observed, with reference to Mr. Terry's remarks, that his own experience led him to prefer the hydraulic riveter to the air-riveter, as it closed the holes more effectually, and was equally portable if not more so. The Author had stated that the pipe-line should be above ground if possible; but he did not say why. Mr. Webster thought that if the pipe-line had to be laid such a distance as was mentioned in the Paper—from 500 yards to a mile—it would be much more convenient to place it in a trench, when the quay space and approaches would be practically free and unencumbered with overhead pipes and supports. The Author had also said, "Either sluice-valves or ordinary steam-valves are used on pipe-lines; the latter are to be preferred, as they show at a glance whether they are open or shut." He did not understand what sort of steam-valves the Author referred to as showing whether they were open or shut; the steam "cock," which was used for smaller pipes, showed by the saw-cut on the top of the plug whether it was open or shut, but the ordinary steam "valves" only indicated their position approximately. There was a further statement in the paper: "The condition of the ground on which the tanks are placed will also to a considerable extent affect the design, the strength of the plates," &c. He wished to know why a petroleum-tank should be treated differently from any other structure. In most cases, the foundation and the superstructure were each considered to have their own functions to perform, the design of the superstructure being based upon considerations entirely independent of those relating to the foundations, the latter, however, being sufficiently strong to carry it. The thickness of the

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plates, and the details of the riveting, he should think would be governed chiefly by the hydrostatic pressure of the liquid, the diameter of the tank, wind-pressure, and the load on the roof, a large factor of safety being adopted on account of corrosion, &c. The foundations, he considered, were entirely dependent upon the nature of the ground, and should be treated in an exactly similar manner to those required for the same distributed load, whether a petroleum tank or any other structure, bearing in mind that on account of pipe and other joints there must be no subsidence. It was further stated in the Paper that the man-holes should be of wrought-iron or steel, but he saw no reason for such a statement. When there was a great pressure to withstand, as in a modern steam-boiler, it was no doubt advisable to use these materials; but for the comparatively small pressure in a petroleum tank, he should consider cast-iron was quite strong enough, and as it was much cheaper, and was capable of withstanding the corrosive action of the oil better than either wrought-iron or steel, he should prefer it. He would be glad to know from the Author what special advantage he considered the Worthington pump to have over those of other well-known makers; and whether the extravagance in the fuel to which he referred was due to the construction of the pumps or of the boiler. Mr. Webster

Mr. Edwin N. Henwood said the Author had remarked that if tanks were sufficiently tight to hold water they would hold oil. One of the managers at the works of Messrs. Sir W. G. Armstrong, Mitchell & Co., had told him it was found necessary to have the rivets far closer together to hold oil than for simply holding water; and Mr. Henwood thought it would be found that was the case. With regard to the hose described, he wished to ask if it had been found possible to coat it with a material which would prevent the oil from going through it, and also whether the Author had used leather, as he believed it was in consequence of the oil being left in the hose that it decayed. With reference to Molyneaux composition being largely made of shellac, perhaps the Author would say whether it was liable to crack, when there was any motion in the joints. He should be glad also to know the cost of the tank-wagons that were likely to be introduced. Probably a cover on the top of the tank, if constructed so as to allow a current of air to pass underneath it, would be sufficient to prevent any heating effect upon the oil, as in the case of the double awnings on vessels in tropical climates. He had on one or two occasions used a form of gauge which avoided the necessity of perforating the tank. It consisted of a siphon which reached Mr. Henwood.

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Mr. Henwood. to the bottom inside, the pipe being brought over the edge of the tank and down to the ground outside, where the end was turned up and furnished with a gland, into which was fitted a long glass tube, so that the exact level in the tank could be at all times seen. A valve was provided at the top of the siphon for the purpose of filling it at the outset, and there were two stopcocks—one at the gland, to prevent loss in the case of the glass tube breaking, and the other (worked by a rod) at the lower end of the pipe inside the tank. The glass tube was protected by a suitable guard.

Mr. Bernays. Mr. JOSEPH BERNAYS said the point that chiefly interested him was the question of foundations in unsatisfactory soil, such as was found in the neighbourhood of London. The Author recommended three or four different kinds for tanks placed on the ground. Ten years ago Mr. Bernays was called upon to design the apparatus and machinery for one of the depots in London, and he then had to deal with precisely the same kind of soil that Mr. Carrington had described by the River Thames, where the ground consisted of about 6 or 8 feet of peat, with bad sand and very unsatisfactory soil underneath it, whilst the tank was to be raised above the ground. He recommended his clients to place it on a foundation that would not yield. In order to do so it would have been necessary to pile, putting a concrete floor or platform on the top. Such a plan would necessarily have been much more expensive than those recommended by the Author. Some differences of opinion occurred, and he did not carry out the work, and therefore did not know what course had been taken. He should like to ask the Author what he would do in a case of that kind where the tank had to be raised 15 feet above the ground. In the arrangement mentioned by the Author the tank was placed on the ground, and the discharge of the oil took place by pumping. In the case that Mr. Bernays had to deal with, the instructions were that the tanks were to be raised sufficiently to enable all the discharge to take place by gravitation; and having very unsatisfactory soil to deal with it was natural that he should prefer to have a perfectly sound foundation, which if it yielded at all would yield equally all round. He had therefore proposed that the tank should be supported by two concentric towers, the larger of which was to be nearly equal to it in diameter. Each tower was to be supported on piles held together by walings, and by 18 inches of concrete across the whole. With reference to the glue-pot mentioned in the Paper, he supposed it was really a hot-water pot rather than a steam-pot.

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Mr. B. P. Stockman remarked that he had had a great deal to do with Molyneaux's paint, and had tested it on various occasions. It was an excellent material, especially for keeping out petroleum or other mineral oils, being quite impervious to them. The question had been asked whether, owing to its composition, it would not be brittle. It was composed of shellac, with a certain proportion of glycerine added which converted it into a leathery substance that was tough and pliable, and excellent for the purpose in question. Mr. Stockman.

Mr. R. H. Brunton found there was very little in the Paper which afforded him any information. Nearly everything that had been described by the Author had been in operation in Scotland for many years. There was a description of one new thing, namely the water-finder, but he could not see why a small pet-cock at the bottom of the tank would not show the presence of water quite as well. The Author was afraid that such a cock might be knocked off by malicious persons, but it could easily be protected by a box under lock and key. He had also expressed a preference for wrought-iron pipes; but Mr. Brunton could not understand why. They were very liable to corrosion when buried in the ground as these must be; and in the Scotch oil-works nothing but cast-iron was used. Molyneaux's composition was averred by the Author to be good for resisting the action of petroleum. It was said, however, to be composed largely of shellac, and if that were the case he should regard it as a most dangerous article to use in a petroleum tank, as the lighter forms of the oil would tend to dissolve it. With regard to the chalk and ballast foundation adopted by Mr. Carrington, their experience in Scotland was dead against any such arrangement, because the wrought-iron bottom resting upon the ballast was very liable to corrosion, and hundreds of gallons of oil might leak away through a hole formed in that way without it being known. With the sanction of the Directors of the Company with which he was connected he had raised all the tanks from the ground with the object of being able to discover leaks when they occurred, and to paint them underneath whenever it might be necessary. The Author had referred to the danger of the distortion of the tanks by the unequal sinkage of the foundations, but had not indicated in what way it was to be obviated. Mr. Brunton's practice was to erect them on a rigid platform of sufficient strength to relieve the weak places of the foundations. He was, however, inclined to favour tanks in the form of a horizontal cylinder, as better calculated to resist torsion, requiring less area of support, and Mr. Brunton.

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Mr. Brunton. gathering the water and other deposits into a more compact space.

Mr. Carrington. Mr. CARRINGTON, in reply to Mr. Redwood's remarks as to whether the ships should discharge the petroleum direct into storage-tanks or into bulk barges, remarked that the course to be followed must depend upon circumstances, many storage depots being inaccessible to tank steamers of the size now in use, and in such cases bulk barges became a necessity. Generally speaking, the more direct and speedy the transference of the oil from the steamers to the storage tanks, the less would be the danger and the waste. In distributing petroleum to the smaller branch depots established on canals, &c., the delivery into bulk barges direct from the steamer might be advantageous provided the oil was in good condition, and a satisfactory plan could be arrived at of agreeing on the total quantity received; until this was done it was necessary that all the oil should pass into the general depot to be measured and reshipped as required. The Author fully agreed with Mr. Redwood as to the necessity of preventing the spraying of the oil and the consequent loss on entering the tanks, and he considered that the best way to do this was to have a very narrow and wide mouthpiece, such as that shown in Fig. 17, Plate 3, placed close to the tank bottom which would quickly become submerged. The use of a layer of water at the tank bottom might save leakage, but was generally objected to by the customers. In the event of a serious leak showing itself in a tank bottom it was a common proceeding to pump in about 3 inches of water, and to maintain this depth by replacing the quantity which leaked out. Respecting the danger to those standing on the curved tops of tanks when taking measurements, a suitably arranged handrail would be a most convenient safeguard, and the objection of the owners to spend money on such details was the only reason he had not adopted them in all cases. Mr. Carrington quite agreed with the opinion that to facilitate the measurement of the contents a number of gauges must be used, but this he strongly objected to on the score of danger. While holding with Mr. Redwood that one object of the erection of storage-tanks was to minimize leakage, he considered that speed of delivery was also a great point to aim at. The amount of oil now imported was largely in excess of that which was dealt with before the days of bulk storage, and therefore the wharfs, dealing with these large quantities brought in steamers of great value, and consequently charging heavy demurrage, were bound to provide more speedy means of unloading the cargoes.

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Mr. Carrington differed from Mr. S. H. Terry as to the advantage of dispensing with the central column when the foundation was a solid one. The use of it greatly cheapened the roof and facilitated erection. Had the foundations been soft and yielding a central column might have been rightly dispensed with. He agreed with Mr. Terry that when columns were not employed, the upper tier of plates carrying the roof girders should be made thicker than $\frac{1}{4}$ inch. He had known tanks, under such circumstances, leak at those points from the strain imposed by the girder attachments. He, also, had found it difficult to get good results from float indicators, but would certainly not care to use the pipe carrying water-gauges described by Mr. Terry, unless the depot was very well protected. In answer to Mr. de Michele the contents were practically open to the atmosphere, the manhole doors not being bolted down with an airtight joint. In this country the loss traceable to evaporation was very slight indeed. In reply to Mr. Webster, the Author preferred to have the pipe-line above ground in order that it might be open to inspection, especially where the fittings were placed. In many cases it was carried from tank-top to tank-top, and being therefore about 15 to 20 feet above the ground caused no obstruction. In ordinary sluice-valves there was nothing to show whether they were open or shut, but with a wheel steam-valve the spindle and wheel showed by their height how far the valve was open. The condition of the ground determined how high the tank might safely be made, the difficulty being to get a good foundation on marshy soil. This question the Author had already dealt with in his Paper. The pile foundation on marshy ground would no doubt support the weight of any ordinary tank, but the cost was so great that it was difficult to induce owners to adopt it. He had given in the Paper the pitch of rivets which he had found to answer, hoping it might be of use to others for work of a similar nature. In reply to Mr. Henwood the rivets of oil-tanks ought certainly to be more closely pitched than in the case of water-tanks, but what the Author intended to convey was that the storage-tanks, having been found not to leak under a water test would under most circumstances be fairly tight with oil. Leather hose was damaged by petroleum, but the canvas hose exhibited at the meeting lasted in a satisfactory manner, and was perfectly tight with a pressure of 40 lbs. per square inch. The Molyneaux composition when well made would not crack if the motion of the joints covered by it was moderate. It was made with a mineral naphtha and not a

Mr. Carrington.

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Mr. Carrington.

vegetable spirit, as in the case of furniture polish. The use of a double roof to the storage tank would probably give good results, but in this country the ordinary tops answered sufficiently well. The siphon arrangement described by Mr. Henwood would not meet the chief difficulty in obtaining a correct measurement, namely, the inequality of level of the tank bottoms. In answer to Mr. Bernays, in the case of a tank to be placed 15 feet above the ground, piling would be inevitable, and on marshy ground such a foundation for a large tank would prove an expensive matter. The glue-pot contained water in its outer casing which was kept to boiling-point by a regulated supply of steam. With regard to Mr. Brunton's remarks, the use of a cock to find the level of the water in a storage tank would be neither efficient nor safe; a box with lock and key would be a very small safeguard in an open field in the country, which was often the situation of the petroleum depot. The water-finder was employed for finding water and foul or dirty oil, and a number of cocks would be required in order to ascertain the level of the water in the manner in which it could be done by this apparatus. Mr. Carrington preferred wrought-iron pipes partly on account of the length of unsupported spans they permitted, and also on account of their flexibility and general adaptability. When used above ground they could easily be painted outside, and internally they were continually covered with oil. Respecting the Molyneaux composition, in the chalk and ballast foundation, the ballast consisted of clean pebbly Thames dredgings placed on a thoroughly rammed chalk platform, coned towards its centre, so that any water which might percolate down to the chalk would run off to the outside. When the ground admitted of it, the Author, as he had said in his Paper, strongly approved of a wall foundation giving access to the bottom of the tanks. In any case such an accident as Mr. Brunton described might be avoided by careful and methodical examination of the tanks from the interior, and when they were placed on the chalk and ballast foundations the least leakage would become apparent, and water could be pumped in to cover the tank bottom. In conclusion he would remark that in some cases the position of the tanks had allowed of a gridiron series of drains being placed below the foundations with a view of obtaining a knowledge of the quantity of leakage from the bottom; they were led into a main cross-drain which delivered its contents into an oil-catcher in which the petroleum floated on the top, and was ladled out at convenient times, the water running out through a dip-pipe. This separator acted very well and was a most valuable fitting for all surface-drains in

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depots where oil was stored in barrels. Another form of petroleum was now being largely stored in bulk, namely lubricating oil; this was pumped into the storage tanks as in the case of refined petroleum, though at a much slower speed, and on barrelling was made clear and bright when necessary by simply heating it in tanks by steam coils. Mr. Carrington.

Correspondence.

Mr. J. Fell Redman, while appreciating the many special contrivances and arrangements of the Author, ventured to suggest the fitting of an additional angle-bar on the outside of the bottom ring, as the caulking edges could always be got at, and the area of bearing-surface would be increased. In the case of bad ground the bottom plating might project all round for several inches beyond the angle-iron with advantage. Whenever repairs were necessary he considered "steaming" for twenty-four hours should be resorted to before allowing men to enter with lights. For a small job, portable electric lamps supplied from storage-cells might be employed, and cold rivets could be used. In view of the great danger of fire spreading, he thought every estate set apart for the storage of petroleum should have a bank of earth all round it, as a rampart. If the Author could describe any method of dealing with fires, the information would be fully appreciated by all who had to do with this useful but dangerous oil. Mr. Redman.

Mr. Bindon B. Stoney observed that the Author had given valuable information about the storage of petroleum, but had made little reference to the all-important subject of protection from fire. In Fig. 6 a tank was shown, apparently surrounded by concrete walls intended to confine the oil in case an explosion, lightning, fire, or other accident should cause it to escape from the tank. A few years since a petroleum depot in Dublin took fire. The oil was stored in barrels, and some concrete in the depot crumbled away under the influence of the strong heat. This showed that concrete walls were not reliable as a protection unless they were shielded from violent heat by earth or sand-mounds heaped around them. Mr. Stoney.

Mr. Thomas Urquhart thought great credit was due to the Author for bringing before the Institution the results of his experience, but regretted that the Paper was confined to terminal storage and barrelling. Without entering into the history of this industry, so well described in Mr. Vasilieff's Paper on "The Oil Wells of Baku," [1] he would give statistics as to the production and Mr. Urquhart.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 405.

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Mr. Urquhart. transport of petroleum products for 1889, in order to illustrate the growing significance of this industry in Eastern Europe, which at no distant date was destined to have an important bearing upon the coal trade. In 1872 the number of wells in use at Baku was 415, and the quantity of crude oil raised was 23,800 tons, the carriage being effected at this period in barrels and skins. In 1878 Messrs. Nobel Brothers introduced the bulk system of transport on sea and land, by which means a great impetus was given to the whole petroleum industry; so that in a few years Russia was able not only to supply her own needs, which had hitherto been done almost entirely by America, but to become the rival of that country in the markets of the old world. The quantity of petroleum exported had become so great that two important fleets of bulk steamers had been built, one on the Caspian Sea and Volga, the whole of which sailed under the Russian flag, the other trading from Batoum to various ports and under various flags. Before entering upon the production and transport for 1889, it might be well to give some data as to the composition and properties of petroleum and petroleum refuse:

Nature of Oil.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen.	Heating Power, British Thermal Units.
		Per cent.	Per cent.	Per cent.	
Crude Russian, light oil .	0·884	86·3	13·6	0·1	22,628
Crude Russian, heavy oil .	0·938	86·6	12·3	1·1	19,440
Russian petroleum refuse .	0·928	87·1	11·7	1·2	19,260

The following Table showed the average percentage of the various petroleum products obtained by the destructive distillation of the crude oil, according to the late Mr. Ludvig Nobel:— [1]

100 Parts Crude Oil.	Parts.	Specific Gravity.	Flashing Point in Degrees Fahrenheit.
Benzine (light oil)	1	0·725	14
Gazoline (light oil)	3	0·775	32
Kerosine (illuminating oil)	27	0·822	77
Soliarovi (lubricating oil)	12	0·870	212
Veregenni (lubricating oil)	10	0·890	302
Lubricating oil	17	0·905	347
Cylinder-lubricating oil	5	0·915	392
Vaseline	1	0·925	
Residuum (liquid fuel)	14		
Loss.	10		

[1] The Region of the Eternal Fire. Marvin, p. 246.

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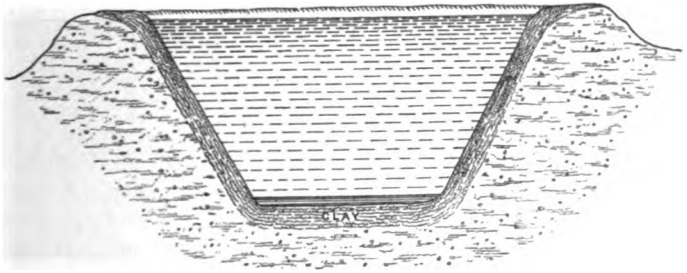
In practice the distillers did not extract each article, as to do so would cause delay in the working of the retorts, and there was no market for some of them. The ordinary commercial yield was as follows:—From every 120 lbs. weight of crude (3 poods Russian) there was obtained 40 lbs., or 33 per cent. illuminating Mr. Urquhart.

Fig. 2.

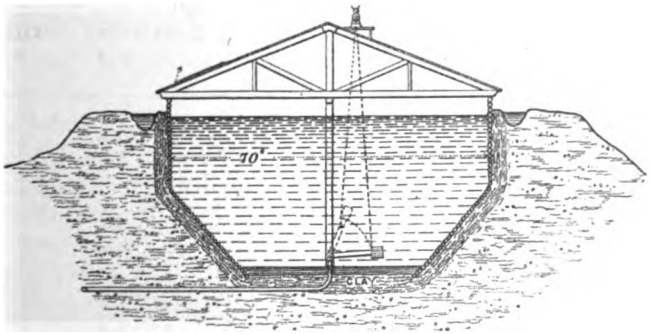


OPEN EARTHEN RESERVOIR. CAPACITY, 16,100 TONS.

oil, 60 lbs. or 50 per cent. refuse (liquid fuel), the remaining 20 lbs., or 17 per cent., being loss.

There were several systems in use for the construction of reservoirs. The most crude were made of earth and wood, with a water moat all round outside, *Figs.* 2 and 3. Others were built of

Fig. 3.



COVERED WOODEN RESERVOIR, BUILT IN EARTH. CAPACITY, 5,650 TONS.

stone in mortar, but the most approved reservoirs were constructed of boiler plates of decreasing thickness towards the upper part of the tank as stated by the Author. The roof was usually conical

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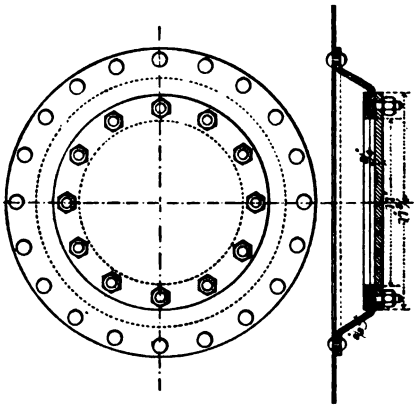
Mr. Urquhart. and consisted of sheet-iron laid upon a light wooden scantling, as in *Fig. 3*, which showed a reservoir for petroleum refuse having a capacity of 5,650 tons; it was 70 feet wide and 112 feet long. All iron reservoirs built at Tsaritsin and at various points along the Grazi-Tsaritsin railway were simply set upon a bed of sand about 6 inches thick on the levelled surface of the ground. They were fitted with lightning conductors. The manhole mountings first used were of cast-iron, but this material having proved dangerous in frosty winters, was replaced at Mr. Urquhart's suggestion by malleable iron. *Fig. 4* showed the form adopted. They were stamped out of ½-inch boiler plates, and fitted with forged covers. In one case a cast-iron cover cracked under pressure, causing some loss of petroleum and much anxiety to the

Fig. 4.



proprietors. In order to ascertain the quantity of water which accumulated on the bottom of the reservoirs, an ordinary gauge glass was mounted as shown in *Fig. 5*. It was placed in a locked-up box, the cocks being kept closed. An attendant generally tried the depth of water once a week if the petroleum was kept long in store. *Fig. 6* showed the water extractor used; this also was kept inside a locked-up box, to prevent its being tampered with. Clack-valves were placed on the end of the delivery-pipes and inside the reservoirs in some cases, as a precautionary measure; they were kept closed by the weight of petroleum on them, and were opened by a chain running over a pulley on the top edge of the reservoir (*Fig. 7*).

When first petroleum was received in large quantities the

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ordinary hydrometer was used for determining the specific gravity Mr. Urquhart.

Fig. 5.

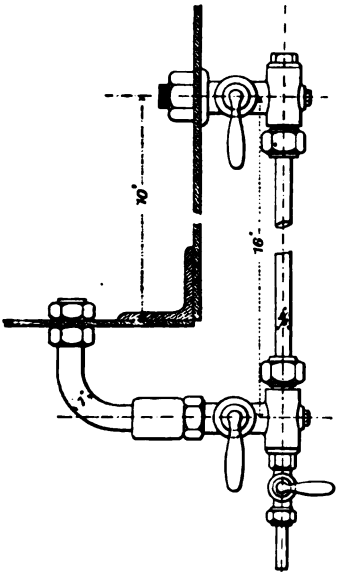


Fig. 6.

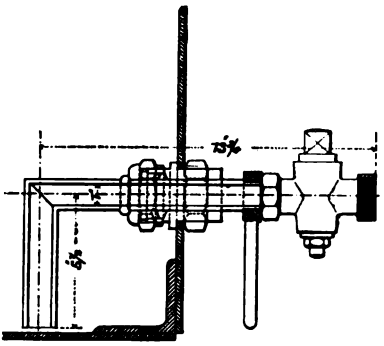
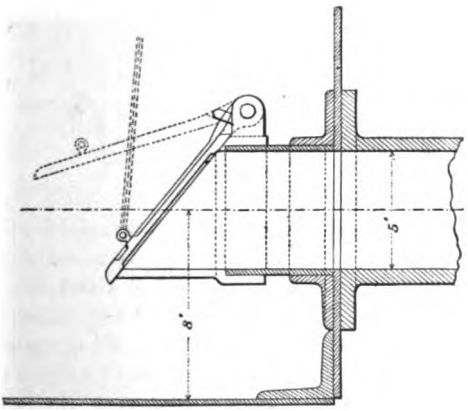


Fig. 7.



of the material, no analysis being made of the carbon and hydrogen contained in the liquid. Westphale's instrument[1] (*Fig. 8*) was

[1] Generally known in England as Mohr's Specific Gravity Balance.—Sec. Inst. C.E.

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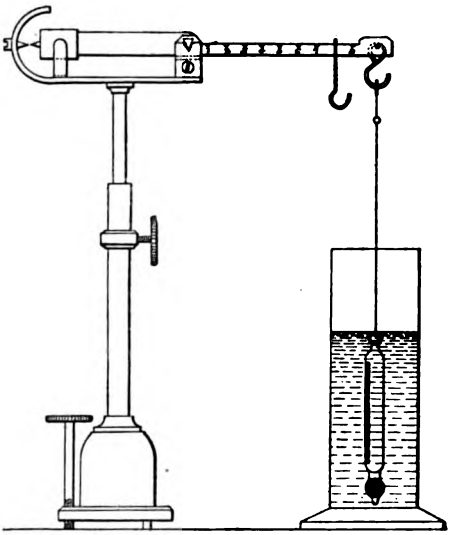
Mr. Urquhart. designed to afford a better and more accurate means of measuring the specific gravity. It consisted of a graduated beam set upon a knife-edge. A quantity of the liquid to be tested was put into a vessel, the instrument being previously set upon a table and levelled by a set-screw in the foot of the stand. When the bulb, which contained a mercurial thermometer, was placed in the liquid, it required some extra weight upon the lever in order to completely immerse it. The extra weight measured the specific gravity of the liquid. This instrument was the only one used

Fig. 8.



on the Grazi-Tsaritsin railway when receiving the petroleum-refuse now employed as fuel in the one hundred and forty-three locomotives, and all fixed boilers, as well as metallurgical furnaces in connection with the line. In making a test, it was usual to allow the liquid to stand for about an hour in order that it might acquire the same temperature as the surrounding atmosphere. The specific gravity of the petroleum-refuse used as fuel for the Grazi-Tsaritsin railway ranged between 0·890 and 0·910 at 63° Fahrenheit.

The following Tables would give an idea of the extent of the petroleum industry in Russia for 1889:—

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TABLE I.—QUANTITY OF CRUDE PETROLEUM RAISED FROM WELLS AND PUMPED FROM LAKES AT BAKU.

Remained on 1 January, 1889, in Reservoirs.	Raised from Wells.	Pumped from Lakes.	Total.
Tons. 90,714·1	Tons. 3,260,813·7	Tons. 47,523·0	Tons. 3,399,050·8

Exported Crude.	Expended as Fuel.	For Distilleries.		
		Pumped by Pipe-Lines.	Carted.	Total.
Tons. 66,437·0	Tons. 229,438·7	Tons. 2,845,100·6	Tons. 29,408·7	Tons. 3,170,385·0

TABLE II.—RESERVOIRS AT BAKU FOR NAPHTHA PRODUCTS 1889.

At the Wells.	Number.	Capacity in English Tons.
Open earthen reservoirs	86	353,644·3
Covered earthen reservoirs (ambars)	18	88,338·7
,, wooden ,,	22	3,437·7
,, stone ,,	64	66,472·2
Iron reservoirs and measuring-tanks above 16 tons (English)	56	30,327·1
Reservoirs in construction	4	10,887·1
Total	250	553,107·1
Reservoirs of various kinds at the distilleries	..	241,935·5
Total		795,042·6

TABLE III.—CAPACITY OF RESERVOIRS FOR ILLUMINATING-OIL.

In Baku.	In Tsaritsin.	In Batoum.
Tons. 192,416·2	Tons. 118,950·0	Tons. 144,790·9

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Mr. Urquhart.

TABLE IV.—TANK VESSELS FOR THE TRANSPORT OF PETROLEUM PRODUCTS.

On the Caspian Sea.

	Number.	Minimum Carrying Power in Tons.	Maximum Carrying Power in Tons.	Total.
Steamships . . .	50	215	1,129	31,774
Sailing	297	..	..	96,034
In construction . .	11	532	1,209	8,613

On the Black Sea.

—	Number.	Minimum Carrying Power in Tons.	Maximum Carrying Power in Tons.	Total Carrying Power in English Tons.
English	22	1,387	3,935	63,356
Russian	2	1,580	1,741	3,321
Belgian	1	..	1,967	1,967
German	1	..	1,935	1,935
Swedish	1	..	968	968

TABLE V.—EXPORT OF PETROLEUM PRODUCTS FROM BAKU DURING 1889.

—	Crude.	Illuminating.	Refuse.	Lubricating.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.
By Caspian Sea	57,416	369,374	1,323,794	5,414	1,755,998
By Transcaucasian Railway	9,021	603,937	103,764	45,806	762,528
Total	66,437	973,311	1,427,558	51,220	2,518,526

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TABLE VI.—EXPORT OF PETROLEUM PRODUCTS FROM BATOUM.

Mr. Urquhart.

To which Country.	Naphtha and N. Refuse.	Petroleum.	Lubricating Oils.	Total.
	Tons.	Tons.	Tons.	Tons.
Africa	..	1,155·5	..	1,155·6
Austria	28·4	99,164·4	1,345·2	100,538·0
Belgium	2,017·5	40,121·4	2,527·1	44,666·0
Bulgaria	..	3,296·6	..	3,296·0
China	..	24,698·0	..	24,698·0
Cochin China	..	2,142·7	..	2,142·7
Egypt	..	24,330·0	..	24,330·0
England	2,028·2	107,435·0	1,115·5	110,578·7
France	6,772·7	625·9	19,812·4	27,211·0
Germany	192·0	15,311·1	6,344·5	21,847·6
Holland	..	4,897·0	1,919·4	6,816·4
India	..	70,785·4	..	70,785·4
Italy	205·9	36,695·0	330·5	37,231·4
Japan	..	21,426·6	..	21,426·6
Java	..	15,650·7	..	15,650·7
Malta	..	797·1	..	797·1
Manilla	..	2,088·7	..	2,088·7
Roumania	..	3,414·5	450·6	3,865·1
Russia	2,141·7	53,130·2	414·1	55,686·0
Siam	..	1,768·8	..	1,768·8
Spain and Portugal	..	149·2	16·1	165·3
Sweden and Norway	..	..	8·4	8·4
Turkey	..	62,105·3	21·2	62,126·5
Total	13,386·4	591,188·5	34,305·0	638,879·9

TABLE VII.—EXPORT OF ILLUMINATING OIL FROM TSARITSIN.

Remained in Stock on 1 January 1889.	Exported during 1889.	Remained in Stock on 1 January 1890.
Tons.	Tons.	Tons.
76,741	236,769	48,102

Mr. CARRINGTON, in reply, while agreeing with Mr. Redman that an outside angle-iron at the lower edge of the bottom tier would increase the bearing area of the tank and be of some service in assisting to support it, considered that the joint could not be so satisfactorily caulked as in the attachment shown in his Paper, and that the extension of the bottom plate beyond the sides would make it liable to leak. Moreover, the plating of the bottom thus extended would have to be considerably thicker than usual to

Mr. Carrington.

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Mr. Carrington.

stand the strain without bending. Steaming would no doubt clear the tank of gas, but would tend to rust the plates inside and possibly lead to the discoloration of the oil. Portable electric lamps were always used for illuminating the interior when the light passing through the manholes was insufficient, and they answered excellently for this purpose. Mr. Carrington considered that earth or clay walls of sufficient height placed round the tanks would secure the neighbouring premises in case of the oil catching fire; but with well-made tanks of ample strength the contents would probably burn out with little damage except to the roof of the structure. To ensure the maximum of safety he would have each tank surrounded with clay or earth walls high enough to contain the whole contents, and would make the distance between them proportionate to their capacity. In depots placed in isolated spots, the tanks themselves, if well made and of reasonable capacity, would give all the protection necessary.

In reply to Mr. Stoney, the tank in *Fig. 6* was so arranged to meet the requirements of the Malta Government, and the walls were intended as shields from the sun as well as for protection from fire. Had the last object only been in view it would have been better to form a large circle with them and have them of less height. No doubt fierce heat would affect concrete, and for that reason it was advisable to back the walls with earth or other suitable material. The arrangement adopted, though very costly, would remove all danger from fire. The data and statistics given by Mr. Thomas Urquhart were especially valuable, and the information contained in them was presented in a very convenient form. The Author concurred entirely with Mr. Urquhart's objection to the use of cast-iron for manholes. Wherever these were put in the lower portion of the sides of a tank, this material should be rigidly excluded. The Author had known cases where cast-iron manholes had cracked from the heat of a fire in close proximity to the tank, permitting the contents to run out and add to the conflagration. Happily, in the case in question, the tank was a small one. In the Author's opinion cast-iron manholes should be prohibited. The existence of a clack-valve at the end of the delivery-pipe inside the reservoir would frequently be very convenient, but the Author considered that in any case a good stop-valve should be fitted to the outlet-pipe as near as possible to the tank.

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Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2489.*)

"The Construction of the New Nadrai (Kali Nadi) Aqueduct, Ganges Canal."

By William Good, M. Inst. C.E.

This aqueduct carries the Lower Ganges canal over the Kali Nadi stream. It was constructed to replace an older work, an account of the failure of which was published in the Minutes of Proceedings, vol. xcv. p. 283. The Paper in question also described the design for the new aqueduct; the present communication will therefore be confined to an account of some modifications in that design, and to a description of the execution of the existing work. (Plate 4, Figs. 1 to 6.)

It was intended to lay a flooring of concrete blocks 5 feet deep so as to limit scour in the river-channel to a depth of 10 feet below the river-bed. When, however, it was found that the stratum of clay which extended under the whole site was nowhere of a less thickness than 7 feet, and was of a hard and tenacious composition, the sunken concrete flooring was omitted, and now the clay stratum is depended on to stop erosion at its upper surface. The position of this natural flooring is fortunate, lying as it does 26 feet below the river-bed, and about a similar distance above the base of the wells. It allows an interval for scour, and, at the same time secures a sufficient depth of wells in the soil when the floods are doing their worst. The side bays and front of the river-wings are protected by a flooring of brickwork blocks 3 feet deep. This precaution was adopted with the object of preventing percolation from the canal that may follow deep scour in the side bays. The above constitute the chief modifications of design made during construction. Minor alterations will be more conveniently referred to further on.

Well-Foundations. (Plate 4, Figs. 5 and 6.)

During the construction of the foundations, and especially during the well-sinking, it was ascertained that where wells are so closely grouped, a looseness of soil round them is produced, and

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little dependence can be placed on side-friction as a factor in bearing the load. The aqueduct-wells never attained the condition of being entirely supported by side-friction; there was always some supporting soil under the well-curbs while they were being sunk, and therefore the net amount of side-friction could not be ascertained. It was however repeatedly proved to be less than $1\frac{3}{4}$ cwt. per square foot of skin-surface. Neglecting then side-friction, the pressure on the foundations from the completed work and its full load of water is 4 tons on the square foot. The test-loads applied to seven of the wells after they had been hearted amounted to a pressure of 6 tons on the square foot, and the resulting subsidence was as follows:—

	Inch.
Mean	1
Least	$\frac{6}{10}$
Greatest	$1\frac{1}{4}$

A more detailed statement of results is given in Appendix A. Finding the subsidence so small the laborious and obstructive process of test loading was discontinued.

The total quantity of well-sinking was 15,019 lineal feet, or nearly 3 miles. Of this, one-half was through the sand that overlay the clay, and this was done with the greatest facility by Bull's dredgers of $2\frac{1}{2}$ cubic feet capacity, worked by hand power. The plant required for this hand-sinking was of the most simple description, and sinking of from 1 to 2 feet per well per day was easily attained, the wells also going down quite plumb. The well-sinking through and below the clay stratum amounted to 7678 feet, and was all done by steam-power, with heavy dredgers or grabs. The wells may be divided into two classes, viz:—

(*a*) Wells of 20 feet external, and 11 feet internal diameter.

(*b*) Wells of 13 and 12 feet external, and 6 feet 4 inches and 6 feet 2 inches internal diameter respectively.

Each class required its own plant, and considering the delay which the ordering of supplies from England entails, it was obligatory to use the sorts procurable in India.

For sinking the 20-foot wells through the clay the grabs mainly used were those of Mr. Jas. R. Bell, M. Inst. C.E. They weighed when empty $1\frac{1}{2}$ ton, were of the nominal contents of 40 cubic feet, and proved superior to those of the same size of the Bruce and Batho or Hodges patterns. They were worked by steam-hoists supplied by Messrs. Cowans, Sheldon & Co. of 5 tons power, weighing 11 tons. This weight of hoist is about the greatest that can conveniently be shifted, but if a large grab had been procurable, more

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duty could have been got from the hoist. The grab was worked from a gantry erected on the well, and, as it was necessary to give sufficient height for the main chain of the grab to unwind itself without coming on to the top pulley, each gantry was 32 feet high and weighed about 7 tons. These gantries proved very unwieldy where such frequent shiftings in a small space were necessary. *Fig. 1*, page 150, shows the gantry and grab at work.

For sinking the 12 and 13 foot wells through clay, the 10-cubic foot Bell grab was at first used; but this proving inefficient, the 25-foot size was tried at Mr. Bell's suggestion, and this, it was found, did four times the work. This latter grab weighed, when empty, a little less than 1 ton, had a maximum splay of 5 feet 8 inches, and worked freely enough in wells of 6 feet 2 inches internal diameter. The hoists were of the 2½-ton power, by Alley and M°Lellan, and weighed about 2 tons each. For this size of well the gantry was about 25 feet high, weighed about 2 tons, and was shifted with ease.

The dredging by steam power was started immediately the well-curb reached the clay stratum, the well being then about 27 feet in soil, and weighted as will be described below. The average time taken to excavate or dredge through the clay was at the rate of twenty hours continuous working to every 2 feet of thickness of the stratum. To get the well through, however, the grab was kept working in the lower sand until a further void of from 6 to 12 feet deep, depending on the thickness of the clay, was attained; and, if by this time the well had not forced its way through, the process of unwatering effected that end. So tenacious was the clay, that once the well-curb had by proper weighting been seated on it, the unwatering did not lead to "blowing." The well dropped suddenly through the clay, and generally as much as 10 feet. If the well was plumb when it reached the clay, it went through quite plumb, otherwise any divergence was exaggerated by the drop, and correction afterwards was attained only with the utmost difficulty. On account of the small interval (2 feet) between them, it was found obligatory to sink alternate wells through the clay, then stop, and sink the intermediate wells to the final position (about 27 feet) before returning to the wells first commenced. This process led to frequent delays and shiftings of the plant; but the result in the accuracy of position of wells was very satisfactory. This will be seen from the record plan of the wells of pier No. 1 (Plate 4, Figs. 5 and 6), and it may also be stated that in only one or two cases does any one of the two hundred and sixty-eight wells touch another.

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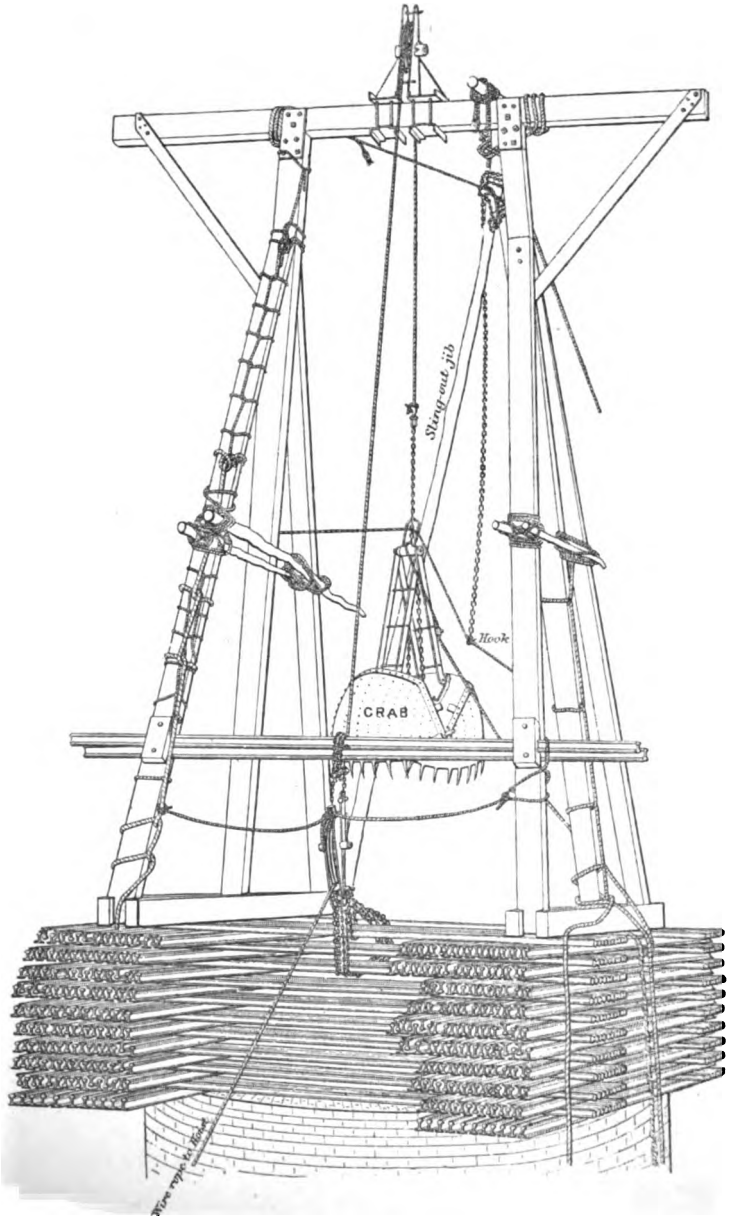
Fig. 1.



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A careful account was kept of the working of the well-sinking plant, and the following general conclusions were arrived at:—

(*a*) The hoists worked 51 per cent. of the total possible time; losing the rest in being shifted, being under repairs, or in consequence of the well-sinking gear going wrong.

(*b*) The average of many observations showed that the time required for each foot of sinking was as follows:—

20-Foot Wells.

	Hours.
With a 40-cubic-foot grab	6·1

13- and 12-Foot Wells.

With a 25-cubic-foot grab	6·3
„ 10 „ „	27·0

Here the advantage of using the largest sized dredgers that will work in a well at once appears; and the only limit to this is the size of hoist, which should not be greater than can conveniently be shifted. Besides the weighting, the other provisions which give quick and satisfactory sinking are:—

(1) Provision of spare wearing parts for the hoists, grabs, and pulleys.

(2) Use of hoists with barrels of 2 feet or more in diameter to avoid wear and tear of wire-rope.

(3) A liberal bonus on the result to the well-sinkers.

The weighting of the wells, previous to sinking them through the clay, was proved to be one of the most important operations. A fully weighted well sinks quickly, does not "blow," and gets thoroughly bedded into the sand in its ultimate position. The weights used for the aqueduct wells were as follows; after allowing for displacement of water:

	Tons.
For a well of 20 feet diameter	525
„ „ 12 „ „	175

Neglecting side-friction, these several weights were equivalent to the following loads per square foot on the greatest horizontal sectional area of the well-curb:—

	Tons.
For a well of 20 feet diameter	3·6
„ „ 12 „ „	3·5

or nearly the ultimate load of 4 tons. The weighting tended to increase as the work proceeded, and where cheaper loading material

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time, and space were available, the weighting might be appreciably increased with advantage.

The final cost of the well-sinking was as follows, taking the rupee as equivalent to 1*s.* 6*d.*, as is done for all prices in this Paper. The amount (£15,960) paid for the purchase of hoists, gantries, grabs, and pulleys, is not included, nor have the proceeds of sales of this plant been credited to the sub-head. It should also be remembered that, although these results were obtained over large quantities, the work was characterized by close grouping of the piers and wells, and costliness of weighting material that enhanced the expense.

HAND-SINKING THROUGH 28 FEET OF UPPER SAND.

	£	*s.*	*d.*
Wells of 20 feet diameter per foot	0	15	0
„ 12 and 13 feet diameter per foot.	0	10	6

SINKING BY STEAM-POWER THROUGH THE CLAY AND THROUGH THE SAND UNDERLYING THE CLAY, IN ALL ABOUT 28 FEET DEEP, PER LINEAL FOOT.

	For Wells of 12 and 13 Feet Diameter.						Wells of 20 Feet diameter, worked by a 40-Cubic-Foot Grab.		
	Worked by a 10-Foot Grab.			Worked by a 25-Foot Grab.					
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
Cost of weighting	0	13	9	0	13	9	1	5	1
„ shifting plant	0	4	6	0	4	6	0	8	4
„ dredging.	3	6	0	0	18	4	1	16	0
Cost of ropes, spars, diving and unwatering gear. Hutting the workpeople and electric lighting	0	7	8	0	6	3	0	12	0
Total rates for sinking in clay. .	4	11	11	2	2	10	4	1	5

Combining the expense of sinking through sand and sinking through clay, the mean rates are as follows, per lineal foot :—

	£	*s.*	*d.*
For 5,643 lineal feet of 20-foot wells	2	8	5
„ 9,376 „ „ 12- and 13-foot wells	1	14	7

The hand dredging was commenced in May 1886, the steam dredging in February 1887, and the whole was completed in May 1888, or at the rate of 24 lineal feet per working day. The largest quantities executed in any one month were 1,349 lineal feet of mixed sinking in July 1887, and 1,089 lineal feet of sinking through clay alone in February 1888. Messrs. W. B. Gordon and

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C. H. Hutton, Assoc. MM. Inst. C.E., were, each in his turn, in charge of the well-sinking work,

The well-curbs are of wood, which was got from the forests of the Kumaon Babar as the only place where sufficiently large scantlings could be obtained. A good deal of time was saved by using wood instead of iron, and even the 20-foot diameter curbs were sufficiently stiff. The rectangular scantlings of wood were swung on a specially devised table, and cut by band saws, so as to fit accurately into their places in the curb. The usual crating of vertical iron bars, about 6 feet apart, connecting the well-curb to the brickwork steining of well to the top, and horizontal rings of iron plates binding the brickwork cylinder together at 8 feet intervals in height, was built into the thickness of well-cylinder. The cost of this crating is included in that of the well-curbs.

The bricks and lime for the brickwork, of which the aqueduct is mainly built, were manufactured specially for the work, and close to the site. The bricks are red in colour, stand a tensile strain of 396 lbs., and a compressive strain of 1,230 lbs. per square inch. The lime was made from kunkur, a material which is very easily procured all over Northern India. The average composition of that used at Nadrai was :—

Carbonate of lime	48·5
„ magnesia	3·0
Iron	2·0
Clay	13·0
Sand	33·5
	100·0

The kunkur was broken to pass through a ring of 1½-inch diameter with the object of freeing its coralline interior from sand as much as possible, and was afterwards burnt in continuous kilns with coal; the burnt kunkur comes out as hard as ordinary chalk. It was then reduced in an F-size Lucop's pulverizer so as to pass through a screen of 6 meshes, and where specially good lime was required, of 10 meshes to the lineal inch. The mortar was all prepared in pan mills worked by steam, and for the permanent brickwork was not mixed with sand or foreign material of any kind. The results of experiments made with it may be summarized as follows. After twelve months the mortar stands nearly as high tensile strain, and after six months nearly as high compressive strain, as the bricks bear. The adhesive strength of the mortar to the bricks amounts to only one-sixth of the tenacity or cohesive strength

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of the mortar itself. The maximum stress at the crown of main arches, neglecting the concrete backing, is 200 lbs. per square inch, while slabs of the mortar used require 1,100 lbs., and of the bricks 1,230 lbs. to crush them; therefore, a factor of safety of between 5 and 6 is here obtained. The stress at the crown of the arch, just after the centre was struck, was 90 lbs., while the mortar at that age (4 days) begins to shale at 240 lbs.

The following were the final rates for materials and brickwork:—

	s.
Coal after carriage of nearly 500 miles by rail, per ton . .	30·0
Raw kunkur fit to load in kilns, per cubic yard	2·43
Ground lime, including cost of storing a supply for monsoon season, per cubic yard	10·8
Bricks of size 9⅞ × 4⅞ × 2¾, including carriage by rail 6 miles to the works, and loss on breakages	18·3
Brickwork, including that in main arches, including also cost of all scaffolding, but excluding centerings, per cubic yard	12·1

Composition of Concrete used.

It was originally intended that the hearting of the wells should be of concrete composed of 25 parts ballast, 3 parts sand, 6 parts lime; and in order that the filling should be done "in the dry," it was proposed to follow the procedure successfully carried out on the Narora Weir Works, of skipping a plug of rich cement concrete into the bottom of the wells. As soon as this plug had had time to set, the well was to be pumped dry, and the main portion of the concrete laid and consolidated. In the case of the aqueduct, however, the weight on the foundations was considerable, and it was necessary to guard against any subsidence, so that it was of paramount importance to secure a thorough bedding of the concrete around, and if necessary, under, the base of the wells. It was considered that this could be best effected by lowering the whole mass as quickly as possible, so that the weight of the material in a plastic state might compress its lower layers, and thus secure a thorough filling of all spaces, and assist the setting of the concrete. This decision necessitated that it should be lowered through the water, and therefore that it should be of a different composition from that above described. In concrete where ballast is in excess, the lime is apt to be washed out, and a large proportion of it "killed." To prevent this the use of sand in larger proportions was suggested by Mr. Beresford, superintending engineer. Experiments proved that—

(1) Sand concrete was distinctly superior to ballast concrete of about the same cost.

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crete the decrease in strength with a smaller
1 of lime to 2 of sand was very marked.
water when it cannot be consolidated
ted to a steady pressure.
te actually used in the hearting
Fig. 6):—
nd concrete composed of 1

ortar.
of the well) of ballast concrete,
ete as in (*a*) above, and 1 part of

mortar was put in to prevent springs
concrete, as the tops of the wells in their
about 10 feet below spring-level. The ballast
upper portion because there was a large quantity
on hand, and the proportion used was so moderate
not affect the strength, while it reduced the cost. The
loyed was of the ordinary small grey variety found in most
rivers. It was mixed dry with the lime, and then made
to mortar with the smallest possible proportion of water in a
roller-mill worked by steam. The concrete was lowered in skips
of 18 cubic feet capacity by steam-power. The skips were
specially designed to work with one rope, and to part with the
material bodily on reaching the bottom. The concrete was all
deposited in the middle of the well, and so great was its dis-
tributive properties that soundings at the sides of the well were
never more than 9 inches greater than over the middle.

The cost of the different sorts of concrete used was as follows per cubic yard:—

	s.
Sand concrete	7·71
Pure mortar plug	15·65
Ballast concrete	6·70

Arched Superstructure (Plate 4, Fig. 2).

The main arches cover an area of over 3 acres and weigh over 30,000 tons. In devising centering for such an extent of arch-work, advantage was taken of the aqueduct arches being divided into three groups, of five arches each, by abutment-piers, to work on one group of five arches only at the time. Moreover the width of arches (148·7 feet) being great, a further sa ing was attained by splitting the arches up longi s

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way the central group of five arches is divided up longitudinally into three sections of $\frac{148 \cdot 7}{3}$ feet wide; and, progress having been found too slow, the centerings were extended, and the side groups arched in two sections of $\frac{148 \cdot 7}{2}$ feet. The centerings as extended measured horizontally 75 feet by 60 feet, and were moved on wheels from section to section, and from group to group. For this purpose a very complete system of tramways and pulleys was laid down from spare plant, and the result was that the arches were built in one hundred and seventy-six days, of which twenty-five days only were spent on the six shiftings of the centerings.

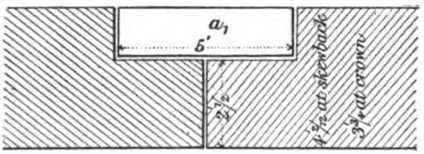
The arches were allowed to rest from three to four days before the centerings were struck, and the subsidence at the crown immediately after the striking was as follows :—

	Inch.
Mean of all arches	0·3
Greatest „	0·6
Least „	0·04

After about nine days the arches had sunk an additional 0·10 inch, and then ceased sinking altogether.

Adjoining sections of arch-work were connected by a cover strip (*a*, *Fig. 2*), arched over after the underlying arches had fully subsided.

Fig. 2.



The hollow spandrels in the body of the work, and the subway under the wide roadway of the left bank greatly lessen the load on the main arches, and to some extent also the load on the foundation. Access to the interior of these hollow spandrels is obtained from the subway on the left canal bank, and at each abutment and abutment pier there is a passage across from one canal bank to the other, through these hollow spandrels. The whole of the interior work is therefore open to inspection.

Provision against Leaks.

To prevent subsidence and leaks from the earthen embankment of the canal channel, the back of the abutment and land-wings is strongly protected with clay puddle down to 4 feet below the main-

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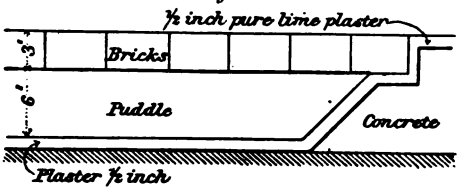
bed, and a row of sheet-piling 4½ inches thick closes the spaces between the well both of the abutment and river-wings to a depth of 19 feet below the same level.

Provision against leaks from the canal superpassage is secured by rendering the internal faces of the revetment-walls on either bank, and the canal-flooring to a distance of 3 feet from the toe of side wall, with plaster composed of Portland cement and very finely pulverized brick in equal portions. As regards the flooring itself, it should be stated that before the staunching medium was laid, the bed of superpassage exposed to view, alternately, strips which happen to have been of an equal length (35 feet) measured along the centre line of canal, and all of the full width (130 feet) of superpassage. One strip exposed that part of the covered surface of the extrados of a main arch that lay 17½ feet on either side of the crown; the next strip exposed a horizontal surface lying over the haunching arches and level with the extrados of these arches at crown. The least depth of the main arches was

Fig. 3.



3¾ feet, and the depth of the haunching arches was 10 inches; the height to floor available for the staunching medium was 7½ inches over crown of the former, and 9½ inches over the latter. Experiment showed that with a head of water equivalent to the full supply in the canal (8 feet) one coat of pure kunkur lime plaster, ½ inch thick, rendered either arch perfectly watertight if the plaster was kept from cracking. Each of the above-mentioned strips was treated differently. The medium over the crown of main arches consisted of concrete composed of selected well-burnt brick ballast, broken to ¾-inch gauge, and ordinary kunkur lime mortar—2 parts of the former to 1 of the latter—and with the upper surface covered with ½ inch of plaster. On the other hand, the staunching medium over the haunching arches consisted of first ½ inch of lime plaster, then 6 inches of good clay puddle, and a 3-inch brick laid flat on the top. The concrete was connected with the puddle-work as shown in *Fig. 3.*

It was considered that the rigid concrete medium would giv extra support to the main arches, while the puddle-medium wo

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be more effectual in preventing leakage in the more exposed haunches. The result has been a practically watertight super-passage extending over 4 acres.

Protecting-Works.

After the embankment had been raised to its full height and water admitted into the canal, it was found necessary to build up the protecting-blocks that front the river-wings to the height of the valley-surface. The river-wings had shown signs of weakness, due, it is believed, to the unfitness of circular well-foundations to carry heavy side pressure.

In order that the work might go on uninterruptedly the site was surrounded by an embankment to keep out floods; and electric light was brought into use when the more important works, such as well-sinking and arch-work, were in progress.

Quantities and Cost.

The following statement shows the quantities of the principal items of work done:—

Description.	Largest Quantity done in any One Month.	Quantity done altogether.
Earthwork, wet and dry, cubic yards .	120,000	3,700,000
Clay puddle, cubic yards	13,000	130,000
Concrete „	6,000	40,000
Brickwork „	9,500	176,000
Well-sinking, lineal feet	1,389	15,019
Bricks used	..	58,100,000
Lime manufactured, cubic yards. . .	4,000	58,000

The main aqueduct cost £210,536; the subsidiary works £45,077; establishment £58,205; and tools and plant £51,600. After deducting the proceeds of sales of plant and stores (£13,125) the net total cost comes to £352,293, being less than the estimate by £22,618.

The work was commenced in September, 1885, and was completed ready to carry a supply of water on the 5th of October, 1889, or only four days beyond the date which had been fixed for it when the estimates were being framed four years previously.

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The design and a complete set of working drawings and estimates were made by Colonel F. J. Home, R.E., and his personal assistant, Mr. M. Nethersole. Messrs. A. J. Hughes and J. S. Beresford were the Superintending Engineers longest in charge of the canal to which the aqueduct belonged. The staff actually employed on the work was deputed from the general establishment of the local Irrigation Branch. The Author was in divisional charge during the greater portion of the time the work was under construction. In addition to the sub-divisional officers already mentioned, the following were longest engaged on the aqueduct:—Mr. W. A. Francken, in charge of workshops and engines; Mr. N. F. Mackenzie, in charge of materials; Mr. A. L. Webb and Mr. A. C. Polwhele, general duty; Mr. G. E. Coles, in charge of records.

The Paper is accompanied by three tracings on linen and a series of photographs, from which Plate 4 and the *Figs.* in the text have been prepared.

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APPENDIX A.—RESULTS OF TEST-LOADING THE WELLS AFTER THEY HAD BEEN HEARTED.

Distinguishing Number of Well.	Outside Diameter of Well.	Characteristics of Well.	Sinking in Feet.				Description of Test-Load.	—
			With ¼ Load.	With ½ Load.	With ¾ Load.	With Full Load.		
	Feet.							
88	20	Had blown badly while being sunk. Tested immediately after it had been hearted .	0·015	0·038	0·065	0·0925	1540 tons added to load of brick-work and concrete in well itself . . .	
142	20	Had *not* blown badly, and was a cut-water well, otherwise the same as No. 88 . .	0·040	0·070	0·090	0·11	1,500 tons, Do.	NOTE. — The total test-load including submerged weight of well itself was equivalent to 6 tons on the square foot of well-base.
150	20	Same as No. 142, only that it had been loaded with 800 tons in an unhearted state	(Not available.)		0·04	0·05	1,500 tons, Do.	
Group of four, Nos. 156 to 159	12	These had blown badly in sinking and were out of plumb. While the concreting was in hand lime water flowed out from round the surface of cylinders, showing want of contact between the cylinders and soil. The group had been loaded with 529 tons before hearting . . .	(Not available.)	0·025	0·050	0·07	2,172 tons, Do.	
		Mean subsidence	0·028	0·044	0·061	0·0806		

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(Paper No. 2543.)

"Effect of Temperature on the Strength of Railway Axles."

PART III.

THOMAS ANDREWS, F.R.SS. L. & E., M. INST. C.E.

THE present Paper contains the concluding experiments of the Author's research "On the Effect of Temperature on the Strength of Railway Axles." The subject is one of considerable interest and importance in railway engineering; and he therefore felt it desirable to make an exhaustive investigation into its various aspects.

The experiments now described, which form Set V, relate to the influence of temperature on the resistance to concussion of railway axles, when submitted to a recurring impact energy of 5 foot-tons. It may be remarked that in the observations in Part I of the research[1] the impact energy was 10 foot-tons at each blow, and in Part II[2] it was only 2½ foot-tons for each blow. The method adopted in the present part of the investigation was generally the same as that described in Part II. To preserve uniformity for purposes of comparison, the twenty-nine best fagotted-scrap railway axles used were in every respect similar, both as regards material and manipulation, to those employed for the observations of Part I and Part II. They were made at the Wortley Iron Works, near Sheffield, and were of the following dimensions:—

	feet	inches.
Total length of axle	7	3½
Length from centre to centre of journals	6	6
Length of wheel seats	0	10⅞
Length of journals	0	7½
Length of end collars	0	1
Diameter of middle	0	4½
Diameter of wheel seats	0	5⅛ full.
Diameter of journals	0	3¾
Diameter of end collars	0	5½

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 340.

[2] *Ibid.* vol. xciv. p. 180.

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Each pair of axles (*i.e.*, one for the warm tests and the other for the cold tests) was made from the two halves of the same fagot, so as to have a uniform and homogeneous structure for purposes of comparison.

For convenience the experiments are divided into Set V, Cold Tests, and Set V, Warm Tests; the former showing the influence of a temperature of 0° Fahrenheit on the impact resistance of axles, and the latter that of a temperature of 100° Fahrenheit under similar conditions.

Set V.—Cold Tests. (Table I.)

Eighteen axles were tested in this set of experiments. They were allowed to cool gradually to their temperature of normal rigidity, viz., the atmospheric temperature at the time they were made, which is given in Table I; they were then buried separately in a heap of about 30 tons of snow for periods stated in the Tables. At the end of that time each axle was removed and placed in a cooling cage, which was surrounded with a large quantity of a freezing mixture, composed of two parts snow and one part by weight of salt, for thirteen hours, or until the metal had acquired the temperature of 0° Fahrenheit. It was then removed and placed on the impact testing apparatus on bearings 3 feet 6 inches apart, and received one blow on the centre from a tup weighing 1 ton and falling from a height of 5 feet. The extent of the deflection between the bearings was carefully taken, and the axle put back in the freezing mixture for fifteen minutes; it was afterwards placed on the bearings half turned over, and again tested in the manner described, by the falling weight. It was always replaced in the freezing mixture for fifteen minutes after each blow, so as to make sure of its being kept at a temperature of 0° Fahrenheit throughout the tests, and the operation was repeated until fracture occurred with the results recorded in Table I.

Set V.—Warm Tests. (Table II.)

Eleven axles were tested in this set in the following manner, for comparison with the Cold Tests of Set V. After forging they were allowed gradually to cool to the temperature of normal rigidity, and were placed in a large water bath, which was gradually raised to 100° Fahrenheit. Each axle was then removed to the impact-testing apparatus and immediately tested in the manner previously described, with one blow upon the centre from a tup

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weighing 1 ton falling from a height of 5 feet, the bearings being 3 feet 6 inches apart. Between the blows each axle was half turned over, and was also replaced for fifteen minutes in the water bath. The deflections between the bearings were carefully measured after each impact, and the extent of the distortion from the original circular form of the axles, arising from the continued concussion, is also given where necessary. The results of this series of observations are recorded in Table II, p. 174.

The mean force of concussion resulting from each impact was ascertained as follows:—

h = height of free fall in feet. } thus $h\,w = \mathrm{W}$ = "energy," or work
w = weight of test ball. } in foot-tons.
x = extent of deflections between bearings.

$$\text{then F (mean force)} = \frac{\mathrm{W}}{x} = \frac{h\,w}{x}$$

The results of these experiments show that whereas at a temperature of 0° Fahrenheit, a total average mean force of 179·670 tons was sufficient to cause the breaking of the axles, at a temperature of 100° Fahrenheit, a total average mean force of 428·333 tons was requisite to produce fracture. In other words the resistance to concussion of the axles, at a temperature of 0° Fahrenheit, was only about 42 per cent. of what it was at a temperature of 100° Fahrenheit.

The average total deflection at a temperature of 0° Fahrenheit was 6·48 inches, as against 15·06 inches with the axles at 100° Fahrenheit, under the conditions stated; this represents an ultimate reduction of flexibility, under the test of impact, of about 57 per cent. for the cold axles at 0° Fahrenheit compared with the warm axles at 100° Fahrenheit.

Mr. Herbert Tomlinson, F.R.S.,[1] has demonstrated that repeated change of temperature alone, even within the comparatively moderate range from 100° Centigrade to 17° Centigrade, produces a considerable amount of internal friction between the constituent molecules of the metal, which tends to modify some of its physical properties. He has shown that the electrical resistance and magnetic properties, &c., are influenced by repeated heating and cooling of the metal. He observes that "some of the physical properties of iron wire, even if it has been previously well annealed, can be considerably modified by repeatedly raising the metal to the temperature of 100° Centigrade, and suffering it to cool again. The internal friction, for instance, of a torsionally oscillating iron

[1] "Philosophical Magazine," vol. xxix. p. 77.

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wire can be largely and permanently reduced by this process." ". . . . The cooling exerts an influence as well as the heating."

General Summary of Results.

The constant internal friction produced by frequent alternations of temperature, apart from the jars and concussions of wear and tear, tends in course of time to alter to some extent the properties of iron and steel axles. Steel being more sensitive to this influence than wrought iron, becomes more liable to alteration of its physical properties, and to this cause may probably be traced the greater proportion of breakages of steel axles occurring in countries such as India and Canada, where variations of temperature are extreme.[1] In these and other lands, railway axles are exposed to the influence of periodic climatic changes of temperature, and often to considerable diurnal variations. Axles also become brittle and crystalline, as the result of the frequent heavy concussions of wear and tear. Mr. G. Snelus, F.R.S., has recently remarked, "That the intricate changes in the condition of iron were extremely interesting, but were very difficult to follow. There was one condition of masses which he thought they had overlooked in those changes, viz., the crystalline condition of matter. Any one who had ever seen a broken railway axle, and the very large facets that there were in the iron, which no doubt at one time was fibrous, would know, for vibration had an enormous effect in producing crystallization."[2]

The Author undertook this research in order to determine by experiments on a large scale the resistance of metals to sudden concussion at varying temperatures down to 0° Fahrenheit, and at the same time to ascertain, if possible, some of the causes leading to accidental fractures on railways. The investigation has extended over nearly seven years, and the results obtained have from time to time been published in the Minutes of Proceedings,[3] and include also a Paper on "The Effects of Chilling on the Impact Resistance of Metals."[4]

It may be desirable in conclusion to give a brief *résumé* of the

[1] See the remarks on the failure of steel axles in India, by Sir Alexander M. Rendel, K.C.I.E., M.A., M. Inst. C.E., in *The Engineer*, September 19th, 1890, p. 235, and reference may also be made to the recent failures of steel axles on the Canadian Pacific Railway.

[2] "Iron," May 15th, 1891, p. 423.

[3] "Effect of Temperature on the Strength of Railway Axles," Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 340; vol. xciv. p. 180.

[4] Minutes of Proceedings Inst. C.E., vol. ciii. p. 231.

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whole series of observations made in connection with Parts I, II, and III of the research. The following are the Author's general tentative conclusions:—

1. The impact tests with an "energy" of 10 foot-tons on axles at a temperature of 212° Fahrenheit, compared with results at 7° Fahrenheit, indicated an increase of endurance at the higher temperature of about 235 per cent.

2. The impact tests with an "energy" of 15 foot-tons on axles at a temperature of 120° Fahrenheit compared with results at 7° Fahrenheit showed an increase of endurance at the higher temperature of nearly 120 per cent.

3. The impact tests with an "energy" of 10 foot-tons on axles examined at a temperature of 100° Fahrenheit, when contrasted with results obtained at 7° Fahrenheit, demonstrated an increase of resistance at the higher temperature of about 43 per cent., and this increase was, within certain limits, in proportion to the increase of temperature.

4. The impact tests with an "energy" of 5 foot-tons on axles at a temperature of 100° Fahrenheit, gave an increase of resistance of about 138 per cent. compared with the results on axles similarly tested, but at a temperature of 0° Fahrenheit.

5. The impact experiments with an "energy" of 2½ foot-tons, applied to axles at a temperature of 100° Fahrenheit, compared with experiments at 0° Fahrenheit, showed an increased resisting power to concussion at the higher temperature of nearly 88 per cent.

The Author has also found that when axles were subjected to a number of heavy blows the extent of the deflection was more during the earlier blows under some temperature conditions than the deflections produced by the later blows, *i.e.*, the elastic limit of the axles had risen. This progressive decrease of deflection was manifest with the impacts made at the temperatures of 212° Fahrenheit, 120° Fahrenheit, and 100° Fahrenheit, but it was not observable when the axles were at a temperature of 0° Fahrenheit.

The experiments on the "Effect of Chilling on the Impact Resistance of Metals"[1] were of a different nature, and are consequently scarcely comparable with the above results. Amongst other things, however, they showed that a reduction of the impact resistance of metals results from even a single lowering of the temperature through 100° Fahrenheit, more extensive chilling producing considerable reduction of resistance to impact.

[1] Minutes of Proceedings Inst. C.E., vol. ciii. p. 231.

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In the course of the research allusion has been made to alternating changes of temperature in axles owing to journal friction and the effect of this in inducing fracture. It has also been indicated that repeated concussions increase the rigidity of both steel and iron axles, and tend to induce brittleness in the metal.

Careful determinations with delicate apparatus have also been made of the heat dilatations of railway axles at varying temperatures from 0° Fahrenheit, 100° Fahrenheit, 212° Fahrenheit, 392° Fahrenheit, and 572° Fahrenheit, and the detailed results have been given in the former parts of this Paper. It was observed that large forgings, such as railway axles, expanded somewhat unequally in different directions owing to the diversified molecular structure of the forged metal. It was ascertained that wrought-iron axles generally show premonitory signs of destruction previous to final fracture, whereas steel ones appear to break suddenly without previous warning.

Full-sized photographs of most of the two hundred and eighty-six fractures have been taken so as to preserve accurate records of the comparative aspects of fractures occurring at different temperatures. Some of these are reproduced in the Papers by the Author published in the Minutes of Proceedings, and a complete series of the original photographs, in volume form, has been presented by the Author to the Library of the Institution for reference. The appearance of the fractures of the warm tests was found to be of a fibrous character, those of the cold tests having a more fine-grained and crystalline aspect.

It will have been observed that the different sets of experiments were made under varied conditions both of temperature and force of impact, &c., which probably accounts for the somewhat diversified comparative percentages obtained. The results of each set are, however, comparable with themselves.

The Author's conclusions receive confirmation from the recent experiments made in Sweden by Mr. C. P. Sandberg, Assoc. M. Inst. C.E., showing the effect of low temperature on the strength of wrought-iron and steel rails. Mr. Sandberg found that the resistance of steel rails to impact was considerably reduced at low temperatures, and this is also in accord with the Author's experience. In connection with the subject reference may be made to the following accidents which have happened during the occurrence of prolonged low temperatures, and afford a practical accentuation of the Author's results, viz.:—

The serious Newark accident in 1869 from the breaking of a steel tire during severe frost.

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The following particulars also show the increased breakage of steel rails during the cold season of the year in America. The total number of accidents is compared with that due to broken rails—

	1885.			1886.		
	Total.	Broken Rails.	Per Cent.	Total.	Broken Rails.	Per Cent.
First quarter . .	273	23	8·4	447	67	15·0
Second quarter . .	234	10	4·3	218	8	3·6
Third quarter . .	341	4	1·2	259	8	3·1
Total . . .	848	37	4·4	924	83	9·0

Mr. Wallis, Superintendent of the Grand Trunk Railway of Canada, states: "I may say, for Mr. Andrews's information, that that there is no doubt that the breakage both of axles and tires (all other conditions except that of temperature being equal), is greatly influenced by the severity of the climate in winter."

On the Grand Trunk Railway during the year 1884, out of a total of fifty-six broken tender- and car-axles, only twenty-three failed during the summer months, and the remaining thirty-three during the winter season.

Some statistics of the total breakages of tires on German railways in 1887, quoted from *Stahl und Eisen*, in "The Engineer," November 9th, 1888, p. 387, ascribe 13·74 per cent. of the total breakages to low temperature and change of temperature.

Reference may also be made to the fracture on February 27th, 1889, of a steel tire on one of the driving-wheels of the locomotive which caused the train to fall through a bridge at St. George's, Western Ontario, on February 27th, 1889, during the prevalence of low temperature. The breakages of steel tires in Russia are about 50 per cent. more in winter than in summer. Further confirmation is afforded by the following instances, which occurred during the recent severe winter, viz.,—

The fracture of a wagon-axle near Blaydon Station, North Eastern Railway, early in December 1890, atmospheric temperature about 25° Fahrenheit.

The sudden fracture of the Siemens steel driving-axle of the engine of a London passenger train at Kirtle Bridge, near Carlisle, January 8th, 1891; atmospheric temperature at the time about 17° Fahrenheit.

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The fracture of the Siemens steel engine-axle of a passenger train at Abington, Caledonian Railway, February 4th, 1891; atmospheric temperature at the time about 34° Fahrenheit.

The fracture of the Siemens steel axle of a sleeping-car on a Western-bound express on the Canadian Pacific Railway, near Schreiber, in the Lake Superior section of the line, which produced such calamitous results on February 5th, 1891; atmospheric temperature at the time of the accident about − 10° Fahrenheit.

Reference has already been made in the former part of the research to the extent to which increased rigidity of the permanent way during frost probably influences the breakage on railways. The whole of the experiments concur in substantially demonstrating that the resistance of railway axles to impact and concussion, &c., is materially reduced when the metal is at a low temperature; and these experimental results are in accord with practical experience.

Some idea of the difficulties and extent of the investigation is afforded when it is stated that a total number of about two hundred and eighty-six railway axles and forgings, weighing 41 tons 16 cwt., have been tested and destroyed in the various experiments, and about 273 tons of snow, ice, and salt, have been used for the freezing mixtures required.

The present Paper is accompanied by four photographs, which may be seen at the Institution. They illustrate the more crystalline character of the fractures at a low temperature compared with the more fibrous nature of the fractures at the higher temperature, and are somewhat similar to the examples shown in Plates 10, 11 and 12, vol. lxxxvii., and in Plate 10, vol. xciv.

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SET V.—TABLE I.—COLD TESTS.

Number of Blows from Commencement.	Axle No. 102. Tested at 0° Fahrenheit.		Axle No. 104. Tested at 0° Fahrenheit.		Axle No. 105. Tested at 0° Fahrenheit.		Axle No. 106. Tested at 0° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	$1\frac{3}{8}$	44·636	$1\frac{1}{4}$	49·000	$1\frac{3}{8}$	44·636	$1\frac{1}{4}$	49·000
2	$1\frac{3}{8}$	37·923	Broken.	..	$1\frac{3}{4}$	35·286	$1\frac{1}{2}$	41·000
3	$1\frac{9}{16}$	39·400	..	..	$1\frac{9}{16}$	39·400	$1\frac{7}{16}$	42·739
4	$1\frac{9}{16}$	39·400	..	..	Broken.	..	Broken.	..
5	$1\frac{9}{16}$	39·400	..	..	..	..	..	..
6	$1\frac{1}{2}$	41·000	..	..	..	..	..	..
7	$1\frac{7}{16}$	42·739	..	..	..	..	..	..
8	$1\frac{1}{2}$	41·000	..	..	..	..	..	..
9	Broken.	..	..	..	..	..	..	..
Totals. .	$12\frac{1}{8}$	325·498	$1\frac{1}{4}$	49·000	$4\frac{11}{16}$	119·322	$4\frac{3}{16}$	132·739
Total accumulated "energy" in foot-tons . .	40		5		15		15	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction . .	Per cent. 0·69	Per cent. ..	Per cent. ..	Per cent. ..
Maximum diametrical increase .	0·69	1·39	..	1·39

The approximate temperature of normal rigidity was as follows: for Axle No. 102, 47° Fahrenheit; No. 104, 44° Fahrenheit; No. 105, 54° Fahrenheit; No. 106, 44° Fahrenheit.

Previous to commencing to test at 0° Fahrenheit, the axles had been kept in a heap of 30 tons of snow for the following periods, viz.: No. 102, twelve days; No. 104, thirteen days; No. 105, twenty-six days; No. 106, fourteen days.

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SET V.—TABLE I.—COLD TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 107. Tested at 0° Fahrenheit.		Axle No. 109. Tested at 0° Fahrenheit.		Axle No. 110. Tested at 0° Fahrenheit.		Axle No. 112. Tested at 0° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	$1\frac{5}{16}$	46·714	$1\frac{1}{4}$	49·000	$1\frac{1}{4}$	49·000	$1\frac{3}{8}$	44·636
2	$1\frac{9}{16}$	39·400	$1\frac{3}{8}$	37·923	$1\frac{9}{16}$	39·400	$1\frac{3}{8}$	37·923
3	$1\frac{1}{2}$	41·000	$1\frac{1}{2}$	41·000	$1\frac{1}{2}$	41·000	$1\frac{9}{16}$	39·400
4	Broken.	..	$1\frac{1}{2}$	41·000	$1\frac{9}{16}$	39·400	$1\frac{9}{16}$	39·400
5	..	..	Broken.	..	$1\frac{3}{8}$	37·923	$1\frac{1}{2}$	41·000
6	..	..	..	..	$1\frac{9}{16}$	39·400	$1\frac{1}{2}$	41·000
7	..	..	..	..	$1\frac{1}{2}$	41·000	$1\frac{1}{2}$	41·000
8	..	..	..	..	$1\frac{1}{2}$	41·000	Broken.	
9	..	..	..	..	Broken.			
Totals. .	$4\frac{3}{8}$	127·114	$5\frac{7}{8}$	168·923	$12\frac{1}{16}$	328·123	$10\frac{5}{8}$	284·359
Total accumulated "energy" in foot-tons . .	15		20		40		35	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction. .	Per cent. 0·69	Per cent. ..	Per cent. 1·39	Per cent. 0·69
Maximum diametrical increase .	..	1·39	0·69	0·69

The approximate temperature of normal rigidity was as follows: for Axle No. 107, 44° Fahrenheit; No. 109, 44° Fahrenheit; No. 110, 44° Fahrenheit; No. 112, 44° Fahrenheit.

Previous to commencing to test at 0° Fahrenheit, the axles had been kept in a heap of 30 tons of snow for the following periods, viz.: No. 107, fourteen days; No. 109, fifteen days; No. 110, six days; No. 112, nine days.

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SET V.—TABLE I.—COLD TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 114. Tested at 0° Fahrenheit.		Axle No. 115. Tested at 0° Fahrenheit.		Axle No. 116. Tested at 0° Fahrenheit.		Axle No. 117. Tested at 0° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	1 1/8	54·333	1 1/4	49·000	1 3/8	44·636	1 3/8	44·636
2	1 1/4	41·000	1 2/16	39·400	1 4/8	35·286	1 1/16	36·556
3	1 2/16	39·400	1 2/16	39·400	1 3/8	37·923	1 2/16	39·400
4	Broken.	..	1 1/4	41·000	Broken.	..	Broken.	
5	..	..	1 1/4	41·000				
6	..	..	1 1/4	41·000				
7	..	..	1 7/16	42·739				
8	..	..	1 7/16	42·739				
9	..	..	1 3/8	44·636				
10	..	..	1 7/16	42·739				
11	..	..	1 1/4	41·000				
12	..	..	1 1/4	41·000				
13	..	..	1 1/4	41·000				
14	..	..	1 1/4	41·000				
15	..	..	1 7/16	42·739				
16	..	..	Broken.					
Totals .	4 3/16	134·733	22	630·392	4 1/4	117·845	4 1/8	120·592
Total accumulated "energy" in foot-tons . .	15		75		15		15	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction . .	Per cent. ..	Per cent. 0·69	Per cent. 0·69	Per cent. 0·69
Maximum diametrical increase .	0·69	0·69	..	..

The approximate temperature of normal rigidity was as follows; for Axle No. 114, 44° Fahrenheit; No. 115, 44° Fahrenheit; No. 116, 44° Fahrenheit; No. 117, 44° Fahrenheit.

Previous to commencing to test at 0° Fahrenheit the axles had been kept in a heap of 30 tons of snow for the following periods, viz.: Axle No. 114, six days; No. 115 six days; No. 116, seven days; No. 117, seven days.

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SET V.—TABLE I.—COLD TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 118. Tested at 0° Fahrenheit.		Axle No. 119. Tested at 0° Fahrenheit.		Axle No. 122. Tested at 0° Fahrenheit.		Axle No. 123. Tested at 0° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	MeanForce Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	MeanForce Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	MeanForce Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	MeanForce Resulting from each Concussion in Tons.
1	1⅜	44·636	1¼	49·000	1⅜	44·636	1⅜	44·636
2	Broken.	..	1 9/16	39·400	1 11/16	36·556	1¼	35·286
3	..	..	Broken.	..	1⅜	37·923	1⅜	37·923
4	..	..	..	..	1⅜	37·923	Broken.	
5	..	..	..	..	Broken.			
Totals .	1⅜	44·636	2 3/16	88·400	6 5/16	157·038	4¼	117·845
Total accumulated "energy" in foot-tons . .	5		10		20		15	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction . .	Per cent. 1·39	Per cent. ..	Per cent. ..	Per cent. ..
Maximum diametrical increase .	..	1·39	1·39	0·69

The approximate temperature of normal rigidity was as follows; for axle No. 118, 44° Fahrenheit; No. 119, 45° Fahrenheit; No. 122, 45° Fahrenheit; No. 123, 45° Fahrenheit.

Previous to commencing to test at 0° Fahrenheit, the axles had been kept in a heap of 30 tons of snow for the following periods, viz.: Axle No. 118, eight days; No. 119, seven days; No. 122, eight days; No. 123, eight days.

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SET V.—TABLE I.—COLD TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 127. Tested at 0° Fahrenheit.		Axle No. 128. Tested at 0° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	$1\frac{5}{16}$	46·714	$1\frac{3}{8}$	44·636
2	$1\frac{3}{8}$	37·923	$1\frac{11}{16}$	36·556
3	Broken.	..	$1\frac{3}{8}$	37·923
4	..	..	$1\frac{7}{16}$	42·739
5	..	..	$1\frac{1}{2}$	41·000
6	..	..	Broken.	
Totals . . .	$2\frac{1}{16}$	84·637	$7\frac{3}{8}$	202·854
Total accumulated "Energy" in foot-tons . . .	10		25	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction .	Per cent. . ..	Per cent. ..
Maximum diametrical increase . .	0·69	1·39

The approximate temperature of normal rigidity was as follows: for Axle No. 127, 45° Fahrenheit; No. 128, 45° Fahrenheit.

Previous to commencing to test at 0° Fahrenheit, the axles had been kept in a heap of 30 tons of snow for the following periods, viz.: Axle No. 127, nine days; No. 128, nine days.

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SET V.—TABLE II.—WARM TESTS.

Number of Blows from Commencement.	Axle No. 124. Tested at 100° Fahrenheit.		Axle No. 125. Tested at 100° Fahrenheit.		Axle No. 126. Tested at 100° Fahrenheit.		Axle No. 129. Tested at 100° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	1⅛	37·923	1¼	35·286	1⅛	37·923	1⅛	37·923
2	1⅛	37·923	1 3/16	34·103	1⅛	37·923	1¼	35·286
3	1 3/16	51·526	1⅛	37·923	1⅛	37·923	1 1/16	36·556
4	1 2/16	39·400	1½	41·000	1½	41·000	1 2/16	39·400
5	1½	41·000	1 5/16	46·714	Broken.	..	1 2/16	39·400
6	1 2/16	39·400	1 5/16	46·714	..	..	1 2/16	39·400
7	1 7/16	42·739	1¼	49·000	..	..	1½	41·000
8	Broken.	..	1¼	49·000	..	..	1⅜	44·636
9	..	..	Broken.	..	..	..	1¼	49·000
10	..	..	..	..	..	..	1 7/16	42·739
11	..	..	..	..	..	..	Broken.	
Totals . .	10½	289·911	11 3/16	339·740	6⅜	154·769	15 5/16	405·340
Total accumulated "energy" in foot-tons . .	35		40		20		50	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction . .	Per cent. 0·69	..	..	Per cent. 0·69
Maximum diametrical increase .	..	Per cent. 1·39	Per cent. 1·39	Per cent. 0·69

The approximate temperature of normal rigidity was as follows: for Axle No. 124, 54° Fahrenheit; No. 125, 54° Fahrenheit; No. 126, 47° Fahrenheit; No. 129, 47° Fahrenheit.

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SET V.—TABLE II.—WARM TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 130. Tested at 100° Fahrenheit.		Axle No. 131. Tested at 100° Fahrenheit.		Axle No. 132. Tested at 100° Fahrenheit.		Axle No. 133. Tested at 100° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	1 3/8	37·923	1 3/8	37·923	1 3/4	35·286	1 11/16	36·556
2	1 11/16	36·556	1 13/16	34·103	1 7/8	33·000	1 3/4	35·286
3	1 9/16	39·400	1 11/16	36·556	1 3/8	37·923	1 9/16	39·400
4	1 1/4	41·000	1 11/16	36·556	1 1/4	41·000	1 1/4	41·000
5	1 1/4	41·000	1 9/16	39·400	1 9/16	39·400	1 7/16	42·739
6	1 7/16	42·739	1 1/4	41·000	1 1/4	41·000	1 7/16	42·739
7	1 3/8	44·636	1 7/16	42·739	1 7/16	42·739	1 3/8	44·636
8	1 3/8	44·636	1 7/16	42·739	1 1/4	41·000	1 5/16	46·714
9	1 3/8	44·636	1 3/8	44·636	1 9/16	39·400	1 3/8	44·636
10	1 3/8	44·636	1 5/16	46·714	1 1/4	41·000	1 5/16	46·714
11	1 3/8	44·636	1 3/8	44·636	1 7/16	42·739	1 5/16	46·714
12	1 3/8	44·636	1 3/8	44·636	Broken.	..	1 5/16	46·714
13	1 3/8	44·636	1 3/8	44·636	..	..	Broken.	
14	1 3/8	44·636	1 5/16	46·714				
15	1 5/16	46·714	Broken.					
16	1 5/16	46·714						
17	1 5/16	46·714						
18	1 5/16	46·714						
19	Broken.							
Totals . .	25 9/16	782·562	20 7/8	582·988	17 1/2	434·487	17 3/8	513·848
Total accumulated "energy" in foot-tons . .	90		70		55		60	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

	Axle No. 130.	Axle No. 131.	Axle No. 132.	Axle No. 133.
Maximum diametrical reduction . .	Per cent. ..	Per cent. 0·69	Per cent. 0·69	Per cent. ..
Maximum diametrical increase .	1·39	..	0·69	1·39

The approximate temperature of normal rigidity was as follows: for Axle No. 130, 47° Fahrenheit; No. 131, 47° Fahrenheit; No. 132, 47° Fahrenheit; No. 133, 47° Fahrenheit.

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SET V.—TABLE II.—WARM TESTS—*continued.*

Number of Blows from Commencement.	Axle No. 134. Tested at 100° Fahrenheit.		Axle No. 135. Tested at 100° Fahrenheit.		Axle No. 136. Tested at 100° Fahrenheit.	
	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.	Permanent Deflections taken from between Bearings in Inches.	Mean Force Resulting from each Concussion in Tons.
1	1 5/16	35·286	1 5/16	37·923	1 11/16	36·556
2	1 13/16	34·103	1 3/8	35·286	1 3/8	35·286
3	Broken.	..	1 5/16	37·923	1 5/16	37·923
4	..	..	1 9/16	39·400	1 9/16	39·400
5	..	..	1 7/16	42·739	1 1/2	41·000
6	..	..	1 7/16	42·739	1 1/2	41·000
7	..	..	1 5/16	46·714	1 1/2	41·000
8	..	..	1 5/16	46·714	1 1/2	41·000
9	..	..	1 1/4	49·000	1 3/8	44·636
10	..	..	1 1/4	49·000	Broken.	
11	..	..	1 1/4	49·000		
12	..	..	1 1/4	49·000		
13	..	..	1 1/4	49·000		
14	..	..	1 1/4	49·000		
15	..	..	1 3/16	51·526		
16	..	..	1 3/16	51·526		
17	..	..	1 1/8	54·333		
18	..	..	Broken.			
Totals . .	3 9/16	69·389	23 1/16	780·823	14	357·801
Total accumulated "energy" in foot-tons	10		85		45	

The sectional distortion from a circular form at the point of fracture resulting from the continued concussions is given under:—

Maximum diametrical reduction .	Per cent. 0·69	Per cent. 0·69	Per cent. 0·69
Maximum diametrical increase .	..	0·69	0·69

The approximate temperature of normal rigidity was as follows: for Axle No. 134, 47° Fahrenheit; No. 135, 44° Fahrenheit; No. 136, 44° Fahrenheit.

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(*Paper No. 2536.*)

"Skew Arch Course Traces."

By FRANK HARRIS, B.A., Assoc. M. Inst. C.E.

IN building small skew bridges of brickwork it is generally considered out of the question to bed each course in the arching to the true curve, since this would necessitate cutting all the bricks, as the traces of successive courses are not parallel to each other. The common alternative of building the courses in parallel equiangular spirals is quite unobjectionable when the breadth of the arch is small compared with its radius of curvature. If, however, the breadth is great, and the angle of the spiral is taken so as to give perpendicularity at the centre of the crown-course trace, then the ends of this course will not be perpendicular to the faces of the arch, and will spoil the appearance of the work, even if their position does not give rise to an objectionable obliquity of pressure.

While maintaining the parallelism of the various courses, and thereby avoiding all bed cutting of bricks, there is no reason whatever why these should not be approximations—as near as possible—to the true skew-arch course-trace in other respects. This is effected by drawing one, say the keying-course trace, to the true curve indicated by theory and making all others parallel to it.

It is generally supposed that the calculations necessary for effecting this are elaborate. This is by no means the case. The equation, although it does not admit of a general algebraic solution, can easily be solved with all necessary approximation by one or two trials in a few minutes.

The derivation of the equation may possibly be considered of some interest. It is easily obtained as follows:—The crest line of the cylindrical centering is taken as the axis of x, and the curved surface is supposed to be developed in a horizontal plane. The axis of y is taken at right angles to that of x and passing through one extremity of the crest line.

The trace of any vertical plane parallel to the axis of roadway over the arch, on the centering, is an S-shaped curve cutting the

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axis of x at an angle which is the complement of the angle of skew.

If r = radius of curvature of the centering,
θ = angular distance from the crestline,
ω = angle of skew,

the equation to these lines is—

$$\left.\begin{aligned} x &= a + r \sin\theta \tan\omega \\ y &= r\theta \end{aligned}\right\}$$

or putting $k = \tan\omega$—

$$x = a + kr\sin\frac{y}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\therefore \frac{dx}{dy} = k\cos\frac{y}{r}.$$

The perpendicular curve, which is the course-trace sought, is—

$$\frac{dy'}{dx'} = -k\cos\frac{y'}{r};$$

$$\text{or} \quad \int \frac{1}{k\cos\frac{y'}{r}}\, dy' = b - x';$$

$$\text{or} \ \frac{r}{k}\log_e \tan\left(\frac{\pi}{4} + \frac{y'}{2r}\right) = b - x' \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and this is the equation to any skew-course trace. In the particular case of the central or keying-course trace, putting A = half the breadth of the arch on the skew, $x = A$ when $y = 0$, therefore $b = A$. Now to lay out the crown-course trace in all ordinary cases it is quite enough to calculate the ordinate of the end at the arch face. This is, of course, the intersection of the above curve with

$$x = kr\sin\frac{y}{r};$$

$$\text{or} \ \log_e \tan\left\{\frac{\pi}{4} + \frac{y}{2r}\right\} = \frac{kA}{r} - k^2 \sin\frac{y}{r};$$

an equation which may be easily solved by trial, taking, as a first approximation, a value of y something less than it would be if the curve were drawn in the ordinary way by prolonging a perpendicular to the centre-line of the roadway at the crown of the arch.

The value of y being found, it is only necessary to measure it off

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round the convex surface of the centering to obtain the point at which the end of this crown-course trace meets the face of the arch.

Perpendiculars to the vertical-plane traces at these three known points, being tangents to the curve, and but slightly inclined to each other, enable the trace to be drawn without difficulty.

In this way any of the true course-traces may be obtained. If more than one are used it is best to calculate the two which pass through the obtuse angles at springing. In this case, however, cut bricks or cut keystones would be required for closing in at the crown.

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(*Paper No. 2548.*)

"The Transmission and Distribution of Power from Central Stations by Compressed Air."

By WILLIAM CAWTHORNE UNWIN, B.Sc., F.R.S., M. Inst. C.E.

IN 1888 the Author communicated to the Institution a short Paper on "The Transmission of Power to great distances by Compressed Air."[1] In that Paper the loss of pressure in air mains and the efficiency of transmission were discussed, it is believed, with more theoretical completeness than had before been attempted. It was not within the scope of that Paper to deal with the efficiencies of compressors and air motors, and indeed at that time very little trustworthy experimental information was available as to the waste of work in air machinery. However, for the purpose of examining the practical bearing of the general equations obtained, it was necessary to assume efficiencies for the compressors and air motors, and some special cases of transmission of power were examined in detail. It may now be said that the assumptions made were not very inexact, for such systems of compressed-air distribution as were in operation at that time. In 1889 Professor A. B. W. Kennedy made careful experiments on the system at work in Paris.[2] He has given a summary at the end of his Paper of all the losses of work which he found to occur in one case which was completely investigated. Air compressed at the Central Station, St. Fargeau, to six atmospheres was transmitted 5 kilometres, reduced in pressure to four and a half atmospheres, and used cold in an air motor of about 10 HP. It was found that for 1 indicated HP. expended in the steam cylinder of the compressor, only 0·26 effective or brake HP. was obtained at the air motor. That is, the combined efficiency of compressor, main and motor was 26 per cent. Now in the Author's Paper it had been calculated that with initial compression to 58·8 lbs. per square inch absolute, and transmission a distance of a mile, the combined efficiency of compressor, main and motor might range from 0·33 to 0·39

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 421.

[2] Experiments on the Transmission of Power by Compressed Air in Paris. Report of the British Association, 1889.

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according to the size of main adopted. These results are rather better than that found by Professor Kennedy in the case which he examined. There is little doubt, however, that the air motor experimented on by Professor Kennedy wasted power by leakage.

During the last year or two the systems of compressed-air distribution in Paris and Birmingham have been greatly extended, and similar plans for power distribution in Dresden, Berlin, Vienna, Leeds, and other towns have been proposed. Amongst the schemes submitted to the International Commission for the utilization of Niagara, there were three in which the power was to be distributed by compressed air. Hence the industrial importance of this system may now be considered as fully recognized.

Compressed air has often been used in transmitting power in mines and for tunnelling operations, where rough machinery is generally adopted, and where economy of power is not very important. It is not surprising that in many such cases extremely imperfect compressors and air motors have been used, which, although they did the work required, wasted power extravagantly. It is from such experiences that an opinion has arisen that the efficiency of compressed-air transmission is very low. Better results have been obtained in the large systems for distributing power by compressed air in Paris and Birmingham. But it has been somewhat unfortunate that the types of compressor at first adopted were not such as to yield a high efficiency, and that many of the air motors also were extremely bad. All the older compressors at Paris, and the large ones at Birmingham, are single-stage compressors, with very inadequate means of cooling the air during compression by water-jackets. At Birmingham the air is delivered into the mains at nearly 280° Fahrenheit, and practically the whole work expended in heating the air is wasted.

Now it has been known for a dozen years at least that spray injection into the cylinder is more effective in cooling the air than a water-jacket. There is also a much more powerful means of reducing the temperature of the air during compression. By compressing the air in two or more stages, and cooling it between the stages, the work expended in heating can be very greatly reduced. As early as 1881 the Norwalk Ironworks Company, Connecticut, U.S.A., constructed compound compressors, with an intercooler, with great advantage. Quite recently compound compressors have been made for the Paris system from the designs of Professor A. Riedler, of Berlin, with the result that two-thirds to three-fourths of the work expended in uselessly heating the air in the older machines in Paris is saved.

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the same time investigations have been carried out on the air motors in use in Paris which show that in the construction of these also a considerable increase of efficiency can be secured.

In reconsidering the problem of distributing power by compressed air, especially in connection with the Niagara scheme, the Author found nothing in the general method given in his previous Paper which required revision. But the numerical results need correction in view of the improvements recently effected. Hardly any accurate experimental data were available two years ago. Now the very valuable treatise of Professor Riedler,[1] containing the results of observations carried out in Paris, furnishes a mass of trustworthy experimental results, both on the resistance of mains and the waste of work in compressors and air motors. It appears worth while to re-examine the conditions of distribution of power by compressed air in the light of these new experiments.

Loss of Pressure in the Air Mains.

Hitherto information as to the resistance of air mains has been scanty. The best experiments were those made by Mr. Stockalper on the pipes of the boring machines at the St. Gothard Tunnel. The new experiments carried out by Professor Riedler and Professor Gutermuth on the air mains in Paris are therefore of great value. The Paris mains are larger than any hitherto tried, and by coupling up different mains at night, a length of 10¼ miles could be experimented on.

The main for the older Paris compressing station consists of cast-iron pipes 11¾ inches or 0·98 foot in diameter. It was laid partly in the sewers, which involved the use of a good many bends. Part of the main in the Rue de Belleville is known to be leaky, and there are numerous draining boxes, siphons, and stop-valves which cause resistance. In a more perfectly arranged main no doubt the loss of pressure would probably be somewhat less than in this old one in Paris. In the following investigation Professor Riedler's results are used, but the reductions from them and the conclusions deduced are the Author's. The formula for the flow of air adopted is that given in the Author's Paper on "The Motion of Light Carriers in Pneumatic Tubes."[1]

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[1] Neue Erfahrungen über die Kraftversorgung von Paris durch Druckluft. Berlin. 1891.

[1] Minutes of Proceedings Inst. C.E., vol. xliii. 1876. Also Article on Hydromechanics, Encyclopædia Britannica. Ninth Edition. Hydraulics, §. 84.

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Formula for the Flow of Air in Long Pipes.—Let d be the diameter, and l the length of a pipe in feet; v the velocity of the fluid in feet per second, and h the head lost measured in feet of fluid under the given conditions. Then if the fluid is incompressible

$$\zeta \frac{v^2}{2g} = \frac{d}{4} \cdot \frac{h}{l}$$

$$h = \zeta \frac{v^2}{2g} \cdot \frac{4l}{d}.$$

This formula may be used for the flow of air in pipes, and indeed has been so used by Mr. Stockalper and others when the variations of pressure and density are small, so that mean values can be taken and the variations neglected. Professor Riedler uses this equation also, but with the artifice of dividing a long main into portions calculated separately—a method very cumbrous and not very accurate.

When air flows along a pipe there is necessarily a fall of pressure due to the resistance of the pipe, and consequently the volume and velocity of the air increases going along the pipe in the direction of motion. The effect of the resistance is to create eddying motions, which, as they subside, give back to the air the heat equivalent of the work expended in producing them. The result is that, apart from conduction to external bodies, the flow is isothermal. Generally, in compressed-air systems, the air is delivered into the mains at a temperature above that of the surrounding earth. The excess of heat is parted with by conduction, and the temperature falls to that of the ground, but no lower, for there can then be no further loss of heat by conduction.

Let P = the absolute pressure of the air in lbs. per square foot.
T = the absolute temperature.
G = the weight of the air per cubic foot in lbs.
V = the volume of the air per lb. in cubic feet.

Then,
$$P V = \frac{P}{G} = c T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $c = 53{\cdot}15$ for air. Taking the temperature of 60° Fahrenheit, so that $T = 461 + 60 = 521$—

$$c T = 53{\cdot}15\, T = 27{,}710. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If air is flowing steadily in a pipe, the same weight of air flows across every transverse section per second. Hence, if W is the

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weight of air flowing per second, Ω the area of a cross-section, at which the velocity is u—

$$W = G \Omega u = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

combining (1) and (3)

$$\Omega u P = c T W. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

Fig. 1.

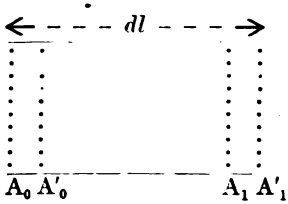

Fig. 1 represents a short length dl of an air-main, between transverse sections A_0, A_1. Let d be the diameter, Ω the cross-section, m the hydraulic mean radius of the pipe. Let P and u be the pressure and velocity at A_0, $P + dP$ and $u + du$ the same quantities at A_1. Let W be the weight of air flowing through the pipe per second. The units are feet and lbs.

If in a short time dt the mass $A_0 A_1$ comes to $A'_0 A'_1$, then $A_0 A'_0 = u\,dt$ and $A_1 A'_1 = (u + du)\,dt$.

By analogy with liquids the head lost in friction measured in feet of fluid is—

$$\zeta \frac{u^2}{2g} \frac{dl}{m}.$$

Let $H = \frac{u^2}{2g}$, then the head lost is

$$\zeta H \frac{dl}{m},$$

and since $W\,dt$ is the flow through the space considered in the time dt, the work expended in friction is—

$$-\zeta \frac{H}{m} W\,dl\,dt.$$

The change of kinetic energy in the time dt is the difference of the kinetic energy of $A_1 A'_1$ and $A_0 A'_0$, that is—

$$\frac{W\,dt}{2g}\{(u + du)^2 - u^2\}$$
$$= \frac{W}{g} u\,du\,dt = W\,dH\,dt.$$

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The work of expansion of $\Omega u\,dt$ cubic feet of air to $\Omega(u + du)\,dt$, at a pressure initially P, is $\Omega\,P\,du\,dt$. But from (3*a*)

$$u = \frac{c\,T\,W}{\Omega\,P}$$

$$\frac{du}{d\,P} = -\frac{c\,T\,W}{\Omega\,P^2},$$

and the work done by expansion is—

$$-\frac{c\,T\,W}{P}\,dP\,dt.$$

The work done by gravity is zero if the pipe is horizontal, and in most cases may be neglected without great error. The work of the pressures on the sections A_0 A_1 is

$$P\,\Omega\,u\,dt - (P + d\,P)\,\Omega\,(u + du)\,dt$$
$$= -(P\,du + u\,d\,P)\,\Omega\,dt.$$

But if the temperature is constant—

$$P\,u = \text{constant}$$
$$P\,du + u\,d\,P = 0$$

and the work of the pressures is zero.

Adding together the quantities of work and equating them to the change of kinetic energy—

$$W\,d\,H\,dt = -\frac{c\,T\,W}{P}\,d\,P\,dt - \zeta\frac{H}{m}\,W\,d\,l\,d\,t$$

$$d\,H + \frac{c\,T}{P}\,d\,P + \zeta\frac{H}{m}\,d\,l = 0$$

$$\frac{d\,H}{H} + \frac{c\,T}{H\,P}\,d\,P + \zeta\frac{d\,l}{m} = 0 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

But—

$$u = \frac{c\,T\,W}{\Omega\,P}$$

$$H = \frac{u^2}{2\,g} = \frac{c^2\,T^2\,W^2}{2\,g\,\Omega^2\,P^2}$$

$$\frac{d\,H}{H} + \frac{2\,g\,\Omega^2\,P}{c\,T\,W^2}\,d\,P + \zeta\frac{d\,l}{m} = 0.$$

For pipes of uniform section Ω and m are constant, for steady

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motion W is constant, and for isothermal flow T is constant. Integrating—

$$\log H + \frac{g\,\Omega^2\,P^2}{W^2\,c\,T} + \zeta\,\frac{l}{m} = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

For $l = 0$, let $H = H_1$ and $P = P_1$

„ $l = L$, let $H = H_2$ and $P = P_2$

$$\log \frac{H_2}{H_1} + \frac{g\,\Omega^2}{W^2\,c\,T}(P_2^2 - P_1^2) + \zeta\,\frac{L}{m} = 0 \quad . \quad . \quad . \quad (6)$$

where P_1 is the greater and P_2 the less pressure. By replacing H_1, H_2 and W—

$$\log \frac{P_1}{P_2} + \frac{g\,c\,T}{u_1^2\,P_1^2}(P_2^2 - P_1^2) + \zeta\,\frac{L}{m} = 0 \quad . \quad . \quad (6)$$

Hence the initial velocity in the pipe is—

$$u_1 = \sqrt{\left\{\frac{g\,c\,T\,(P_1^2 - P_2^2)}{P_1^2\left(\zeta\,\frac{L}{m} + \log\frac{P_1}{P_2}\right)}\right\}}$$

and when L is great, $\log \frac{P_1}{P_2}$ is comparatively small compared with the other term in the bracket. Then—

$$u_1 = \sqrt{\left\{\frac{g\,c\,T\,m}{\zeta\,L}\quad\frac{P_1^2 - P_2^2}{P_1^2}\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

For pipes of circular section $m = \frac{d}{4}$, where d is the diameter in feet. Let $c\,T = 27{,}710$, and let p_1, p_2, be the pressures in lbs. per square inch. Then—

$$u_1 = \sqrt{\left\{222{,}900\,\frac{d}{\zeta\,L}\quad\frac{p_1^2 - p_2^2}{p_1^2}\right\}} \quad . \quad . \quad . \quad . \quad . \quad (7a)$$

This equation is easily used. In some cases the approximate equation—

$$u_1 = \left(1{\cdot}1319 - 0{\cdot}7264\,\frac{p_1}{p_0}\right)\sqrt{\left(222{,}900\,\frac{d}{\zeta\,L}\right)} \quad . \quad (8)$$

may be more convenient.

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If the terminal pressure p_2 is required in terms of the initial pressure p_1, then—

$$p_2 = p_1 \sqrt{\left\{1 - \frac{\zeta u_1^2 \mathrm{L}}{222{,}900\, d}\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

If from a series of experiments ζ is to be found--

$$\zeta = 222{,}900 \frac{d}{u_1^2 \mathrm{L}} \quad \frac{p_1^2 - p_2^2}{p_1^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Before proceeding to calculate the value of ζ from the experiments of Professor Riedler and Professor Gutermuth on the Paris mains, it is necessary to examine the corrections to be made for leakage and the special resistances of the draining boxes.

Loss of Air by Leakage from the Main.—Special experiments were made by Professor Riedler and Professor Gutermuth to determine the leakage loss in portions of the old Paris main. These gave the following results:—

—	I. Southern Section. Central Works to Pl. de la Concorde.	II. Entire Pipe Line.	III. Central Station to Pl. de la Concorde.	IV. Entire Pipe Line.	V. Northern Section. Central Station to Rue de Belleville.	VI. Rue des Pyrenees.
Length in miles .	5·69	10·69	5·69	10·69	0·87	0·34
Initial pressure in atmospheres . .	6·5	6·9	7·0	6·7	6·0	6·1
Terminal pressure .	6·0	5·9	6·43	5·82	5·0	3·7
Loss of pressure per hour in atmospheres	1·5	1·5	0·57	1·32	0·6	0·56
Loss of air in cubic feet per hour, reckoned at atmosphere pressure .	34300	67000	13000	59000	2100	782
Loss of air in cubic feet per mile per hour	6030	6270	2285	5520	2414	2300

It is stated that during trials I, II, and IV, considerable leakage was known to exist at the Central Station and the Rue de Belle-

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ville. In all the trials the air consumed by the clock system and some small motors not stopped is included. Reduced, as shown in the last line, the results are consistent if it is assumed that the leakage was really greater in the sections included in I, II, and IV than in the other sections.

Now, with an initial gauge-pressure of 6 atmospheres and an initial velocity of 30 feet per second, the main would deliver about 600,000 cubic feet of air per hour, reckoned at atmospheric pressure. Then the percentage of loss by leakage per mile per hour would be as follows :—

——	I.	II.	III.	IV.	V.	VI.
Per cent. of air lost by leakage per mile per hour .	1·00	1·05	0·38	0·91	0·40	0·38

Professor Riedler believes that in newer and better-laid mains the leakage is considerably reduced. In any case it appears that the loss is small and practically negligeable except in very long transmissions, at least when the main is delivering a full supply. It should be remembered, however, that the leakage is proportionately greatest in those hours when the pressure has to be maintained in the mains, but the demand for power is small. Where the demand for power is very variable this loss might become an appreciable factor. Looking to the uncertainty as to the amount and law of variation of leakage in different cases, it will be neglected in this investigation, taking the experiments above referred to as a proof that it is not a serious quantity even in the Paris installation, and that in newer mains laid with the experience now gained it would be still less important.

Correction for Loss of Pressure at Draining Tanks.—On some of the mains experimented on by Professor Riedler there were draining tanks at which there was a sensible loss of pressure. The resistance at such a receiver must be analogous to the loss at a sudden enlargement of a pipe, and we may therefore write, if $\mathfrak{P}$ is the pressure lost, p the absolute pressure of the air, and v its velocity—

$$\mathfrak{P} = \zeta_d p v^2$$

where ζ_d is the coefficient of resistance to be determined by experiment. Some experiments were made by Professor Riedler

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on these draining tanks. The following Table gives the results and the calculated value of ζ_d.

Absolute Pressure p.	Velocity of Air in Main.	Observed Loss of Pressure at One Draining-Tank, $\mathfrak{P}$.	Calculated Value of ζ_d.
Lbs. per Sq. Inch.	Feet per Second.		
104·6	19·5	0·94	0·00002363
104·1	19·0	0·95	0·00002527
84·1	28·5	2·42	0·00003543
106·9	24·25	2·14	0·00003404
102·0	18·25	1·00	0·00002943
		Mean. . .	0·00002956

These figures are fairly accordant, and the loss at each draining tank may be taken as—

$$\mathfrak{P} = 0{\cdot}00003\, p v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Experiments by Professor Riedler and Professor Gutermuth on the Resistance of the Paris Air Mains.—The old air mains of Paris consist of cast-iron pipes 30 centimetres = $11\frac{3}{4}$ inches = 0·98 foot in diameter. It was on these that the experiments were made. For the new station wrought-iron pipes of 20 inches diameter are being used. The importance of these experiments lies chiefly in the large scale on which they were carried out. The volumetric efficiency of the compressors was first determined. Then, at different points on the pipe-line, the pressure was observed when the compressors were running at known speeds. On Sundays the whole pipe-line could be coupled up, all work in the city being stopped. The air then passed through the southern main and back by the northern main, a distance of 10 miles. The main is somewhat complicated, having been constructed piecemeal during the gradual extension of the enterprise. In the 10-mile length there are four draining tanks, twenty-three draining-traps or siphons, and forty-two stop-valves. The resistance of these is included in the observed results. It appears, however, that the most serious additional resistance was that of the draining-tanks, and as special experiments were made on these, their resistance can be estimated with very approximate accuracy and allowed for.

The following Table gives the results of the experiments reduced to English measures. The columns marked with an

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EXPERIMENTS ON THE RESISTANCE OF THE PARIS AIR MAIN.

No.	Position of Pipe.	* Length in Miles. l	* Initial Pressure in Lbs. per Sq. Inch p_1 (Absolute).	* Terminal Pressure in Lbs. per Sq. Inch p_2 (Absolute).	$p_1 - p_2$	* Number of Draining Tanks.	Calculated Resistance of the Draining Tanks in Lbs. per Sq. Inch.	Terminal Pressure corrected by deducting Resistance of Tanks.	Corrected Value of $p_1 - p_2$	* Volume of Air passing per Second Reckoned at atmospheric Pressure in Cub. Ft.	Volume of Air per Second at Initial Pressure p_1 in Cubic Feet.	Initial Velocity in Feet per Second v_1.	ζ
I.	Entire pipe line . . .	10·28	106·6	77·2	29·4	4	8·95	86·15	20·45	135·0	18·62	24·69	0·00229
II.	„ . . .	10·28	114·4	78·8	35·6	4	8·45	87·25	27·15	135·5	17·42	23·09	0·00316
III.	„ . . .	10·28	119·4	100·6	18·8	4	4·76	105·36	14·04	109·2	13·44	17·82	0·00280
IV.	„ . . .	10·28	116·1	107·0	9·1	4	2·44	109·44	6·66	79·1	10·04	13·31	0·00255
V.	„ . . .	10·28	114·4	108·8	5·6	4	1·62	110·42	3·98	64·5	8·29	10·99	0·00229
VI.	Rue de Charonne . . .	2·74	116·1	111·7	4·4	1	0·95	112·65	3·45	98·6	12·48	16·55	0·00327
VII.	„ . . .	2·74	119·4	116·9	2·5	1	0·42	117·32	2·08	66·4	8·17	10·83	0·00449
VIII.	„ . . .	2·74	114·4	105·4	9·0	1	1·83	107·23	7·17	135·5	17·42	23·09	0·00345
IX.	„ . . .	2·74	119·4	113·2	6·2	1	1·14	114·34	5·06	109·2	13·44	17·82	0·00397
X.	Fontaine—Station I . .	2·08	102·9	100·5	2·4	..	..	100·50	2·40	109·2	15·60	20·68	0·00214
XI.	Charonne Fontaine . .	5·45	112·5	108·6	3·9	2	1·27	109·87	2·63	79·1	10·34	13·71	0·00184
XII.	Fontaine—Station I . .	2·08	107·7	107·2	0·5	..	..	107·20	0·50	79·1	10·79	14·31	..
XIII.	Station, rue de Charonne	2·75	113·9	110·3	3·6	1	0·71	111·01	2·89	84·2	10·86	14·40	0·00365
XIV.	„ „	2·75	108·3	105·8	2·5	1	0·84	106·64	1·66	89·3	12·12	16·06	0·00181
										Mean			0·00290

Experiment XII. gives a result so anomalous that it is impossible not to suspect some error of observation or record.

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asterisk are those taken directly from Professor Riedler's Tables. The others are deduced from his figures.

The last column gives the values of ζ calculated by equation (10).

It will be seen that the values of ζ are fairly consistent considering the difficulties of the observations. The discrepancies are irregular and obviously due to inconsistencies in the data of the experiments. For instance, experiments XIII and XIV were made on the same main at nearly the same initial pressure. In XIV the velocity was sensibly greater than in XIII, but the loss of pressure is much greater in XIII than in XIV.

Professor Riedler appears to believe that his experiments on the Paris main show that the friction of air in pipes is considerably less than it was believed to be from the results of earlier experiments on a smaller scale. The Author does not think that this is so, but that, on the contrary, when properly reduced they are consistent with previous results, and that all the known experiments fairly support each other. In a paper on the Coefficient of Friction of Air flowing in long pipes,[1] it was shown that M. Stockalper's experiments gave the following results:—

	$\zeta =$
Mean for 0·492-foot pipe.	0·00449
„ 0·656-foot pipe.	0·00377

These experiments, as well as some others given in that Paper, show that the value of ζ for air as well as for water decreases as the size of the pipe is larger. Though experiments on the flow of air are not numerous enough to furnish any very trustworthy law, the Author gave in 1880 the following expression for the value of ζ:—

$$\zeta = 0{\cdot}0027\left(1 + \frac{3}{10\,d}\right)$$

This gives the following values for ζ:—

	$\zeta =$
Pipe 0·492 feet diameter.	0·00435
„ 0·656 „ „	0·00393
„ 0·980 „ „	0·00351

which are only a little different from those deduced from Stockalper's and Riedler's experiments.

Rounding off slightly the mean of Professor Riedler's results, it will be assumed in the remainder of this Paper that, for air flowing

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 299.

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in pipes of not less than 1 foot diameter, $\zeta = 0{\cdot}003$. Putting this value in equations (7) and (9).

$$u_1 = \sqrt{\left\{74{,}300{,}000\frac{d}{L}\frac{p_1^2 - p_2^2}{p_1^2}\right\}} \quad . \quad . \quad . \quad . \quad (12)$$

$$p_2 = p_1\sqrt{\left\{1 - \frac{v_1^2 L}{74{,}300{,}000\, d}\right\}} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Loss of Pressure per Mile of Pipe.—In order to indicate what kind of results this formula leads to, the following cases have been calculated.

1. Given the diameter of the pipe, and the initial pressure and velocity of the air entering the main, it is required to find the loss of pressure in 1 mile of transmission. By simple transposition, putting L = 5,280—

$$p_2 = p_1\sqrt{\left\{1 - \frac{v_1^2}{14{,}072d}\right\}} \quad . \quad . \quad . \quad . \quad (14)$$

Assuming initial velocities of 25, 50, and 100 feet per second, and initial pressures of 50, 100, and 200 lbs. absolute, the following values are obtained :—

Diameter of Pipe.	Initial Velocity v_1.	Values of Terminal Pressure p_2, when			Percentage of Initial Pressure lost in One Mile.
		$p_1 = 50$	$p_1 = 100$	$p_1 = 200$	
Feet.	Feet per Second.				
1·0	25	48·8	97·7	195·4	2·4
..	50	45·3	90·6	181·2	9·4
..	100	26·9	53·8	107·6	46·2
2·0	25	49·4	98·9	197·8	1·2
..	50	47·7	95·4	190·8	4·
..	100	40·1	80·3	160·6	1

The percentage of pressure lost in a mile is the sam
the initial pressure. It must not, however, be assu
loss in 2 miles is double the loss in 1 mile. The el
and the density diminishes going along the ma

It is clear that when the velocity initially
50 feet per second, the loss of pressure beco
distance of a mile. How far that involv
be considered later.

2. Another mode of looking at the

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Suppose the percentage loss of pressure is assumed and the initial velocity calculated. In the following Table this has been done for transmissions to distances of 1, 5, 10, and 20 miles.

Length of Main in Miles.	Diameter of Main in Feet.	Initial Velocity v_1, when the percentage Loss of Pressure in Transmission is				
		1	2½	5	10	20
1	1	16·7	26·3	37·0	52·5	73·1
	2	23·7	37·3	52·4	71·18	100·6
5	1	7·5	11·8	16·5	23·5	31·8
	2	10·6	16·6	23·3	33·2	44·9
10	1	5·3	8·3	11·3	16·6	22·5
	2	7·4	11·7	15·9	23·4	31·8
20	1	3·7	5·9	8·3	11·8	16·0
	2	5·4	8·3	11·7	16·6	22·6

Transmission is possible to the longest distances here assumed at velocities not impracticably low, with losses of pressure which would not hinder efficient use of the air.

Action of the Air Compressors.

When an air compressor is driven by a steam engine, there is a difference between the work done by the steam and the work done on the air, due to the work expended in friction of the mechanism and measured by the difference of area of the indicator diagrams of the steam-cylinder and compression-cylinder. If the compressor is driven by water-power there will also be a corresponding loss in friction of the mechanism, probably not widely different in amount. It will be sufficient here to consider a compressor driven by steam.

Let U be the work expended, measured on the steam-cylinder indicator diagram, and U_1 the corresponding work shown on the compressor-cylinder diagram. Then if η_1 is the efficiency of the mechanism,

$$U_1 = \eta_1 U.$$

It is convenient at present to take U and U_1 to be the work in foot-pounds per pound of air compressed. In Professor Kennedy's tests of some of the older compressors at Paris it appeared that $\eta_1 = 0{\cdot}845$. Experiments by Professor Gutermuth on the new Riedler compressor gave $\eta_1 = 0{\cdot}87$, a result not widely different.

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In all compressors there are some losses of work due to clearance, to imperfect action of the valves, to leakage and to other causes. But unless the machine is badly constructed these need not be large. If the air is compressed to a pressure above that in the mains—as has happened in some cases—there is a loss, for the unbalanced expansion uselessly heats the air; but this again can be kept within narrow limits if the valves act promptly and properly. The chief loss of work in compressors is due to useless heating of the air. It is not, of course, impossible that some of the heat thus generated should be usefully employed. But to make use of it would involve complications. It is said that in Birmingham, where the distance of transmission is not great, some of the heat reaches the motors, and then there is an economy in the amount of air used. But practically in most cases heat given to the air in the compressor is in fact wasted before the air is used for motive purposes. A perfect compressor for power distribution would be one in which the air taken in at atmospheric pressure p_a should be compressed isothermally to an absolute pressure p_1 equal to that in the mains at the compressing station, and then delivered into the mains without valve resistance.

Such a machine working without friction, or clearance, or valve losses, would require for each pound of air compressed an amount of work given by the equation—

$$U_2 = P_a V_a \log_e \frac{p_1}{p_a} \text{ foot-lbs.},$$

where P_a is the atmospheric pressure in lbs. per square foot, and V_a the volume of 1 lb. of air at that pressure.

If, as hitherto assumed, the initial temperature of the air is 60° Fahrenheit,

$$U_2 = 27{,}710 \log_e \frac{p_1}{p_a}.$$

Fig. 2 shows the indicator diagram of such an engine. O A D E is the work done by the atmosphere on the piston in the suction stroke. O B C D A is the work done on the air in the compressing stroke, the compression curve, D C, being a common hyperbola. The work expended in compression is therefore the shaded area, E B C D.

If the air were compressed without any cooling during compression, the compression curve would be an adiabatic such as D F. The work expended in compression would be the area, B F D E. Consequently in that case the area, C F D, would represent the

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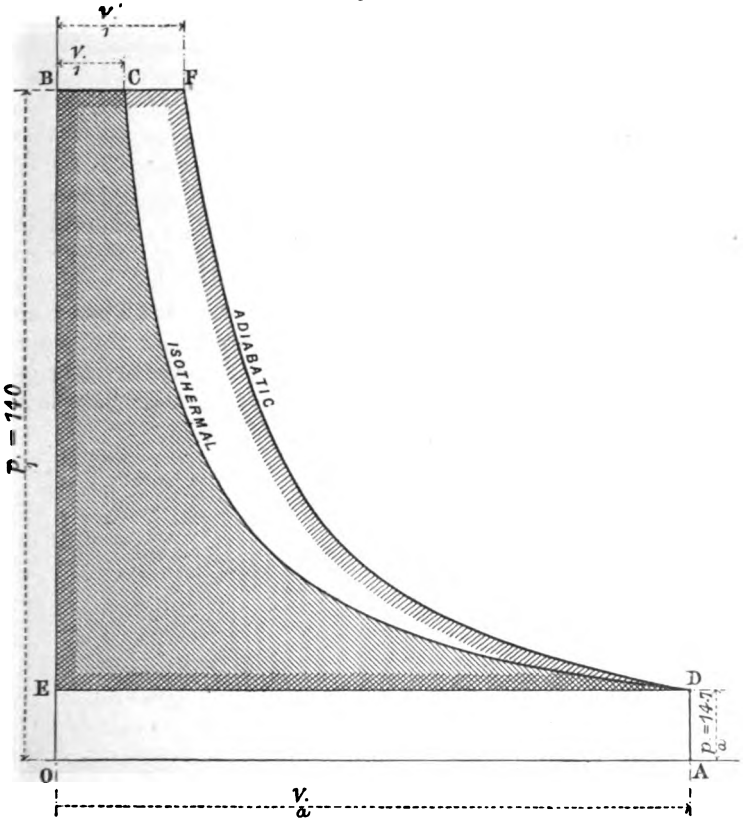
work expended in useless heating of the air. This is easily calculated, for it can be shown that the work expended per pound of air in adiabatic compression is:—

$$\frac{\gamma}{\gamma - 1} P_a V_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

Fig. 2.



ACTION OF COMPRESSOR.

Putting $\gamma = 1{\cdot}41$ and $P_a V_a = 27{,}710$ as before,

$$U'_2 = 95{,}630 \left[\left(\frac{p_1}{p_a} \right)^{0{\cdot}29} - 1 \right] \quad . \quad . \quad . \quad (15)$$

If $\eta_2 = U_2 / U'_2$, then η_2 may be termed the efficiency of the

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compressing process. For simple adiabatic compression, neglecting clearance and friction losses—

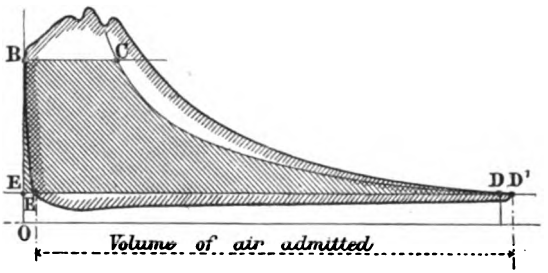
$$\eta_2 = \frac{\log_e \frac{p_1}{p_2}}{3{\cdot}451\left[\left(\frac{p_1}{p_a}\right)^{0{\cdot}29} - 1\right]}$$

This may be called the theoretical value of η_2.

p_1	p_a	$\frac{p_1}{p_a}$	Theoretical Value of η_2.
44·1	14·7	3	0·85
73·5	..	5	0·78
102·9	..	7	0·74
147·0	..	10	0·70

It is clear, therefore, that if the air is not cooled during compression, the efficiency of the process decreases as the pressure to which the air is compressed is greater. Now in most cases the cooling arrangements are very imperfect, and the compres-

Fig. 3.



COLLADON COMPRESSOR. REVOLUTIONS, 104; WORK WASTED, 38·15 PER CENT. OF USEFUL WORK.

sion is nearly adiabatic. Consequently there has been reluctance to use high initial pressures, and this diminishes the facility for distributing power by compressed air. As the other losses besides that due to heating are serious, the whole efficiency of the compressor is considerably less than the values calculated above.

Fig. 3 shows an actual diagram from one of the best of the older Colladon compressors. The shaded area, B C D E, is the

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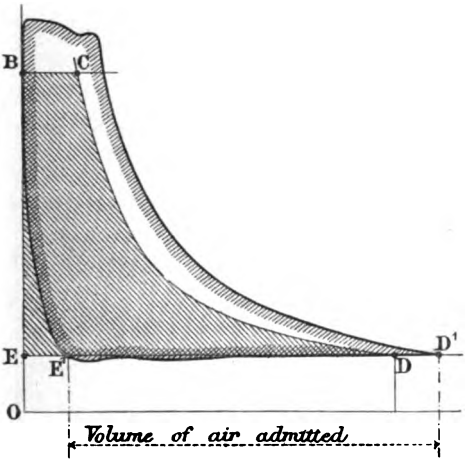
useful work of compression, U_2 corresponding to the area, E B C D in *Fig. 2.* The thick line is the actual indicator diagram. It will be seen that the actual diagram is 38·15 per cent. larger than the isothermal diagram for the volume of air admitted, the difference being due partly to the waste of work in heating the air, and partly to valve resistance, causing a loss of pressure in the suction stroke and an excess pressure during delivery into the mains. In this case η_2 measured from the diagram is 0·72. In several compressors tried by Professor Riedler, the loss of work in the compressing process was twice as great as in this case. *Fig. 4* shows a similar diagram for one of the Cockerill compressors at

Fig. 4.



COCKERILL COMPRESSOR.

Paris. The excess work here is 40·2 per cent. of the useful work, and consequently $\eta_2 = 0·70$.

Obviously part of this loss can be saved if the air is cooled during compression, and all compressors are provided with some means of cooling. Very generally a water-jacket to the compressing cylinder is used, but the action of this is very imperfect. At Birmingham, although the compressors are well water-jacketed, and though the pressure is only 45 lbs. (gauge), the temperature of the air delivered is about 280°. The area of surface of the cylinder is small compared with the volume of air compressed, and air parts with heat to a metal surface slowly. Spray injection into the cylinder answers much better in keeping down the temperature. But it is believed

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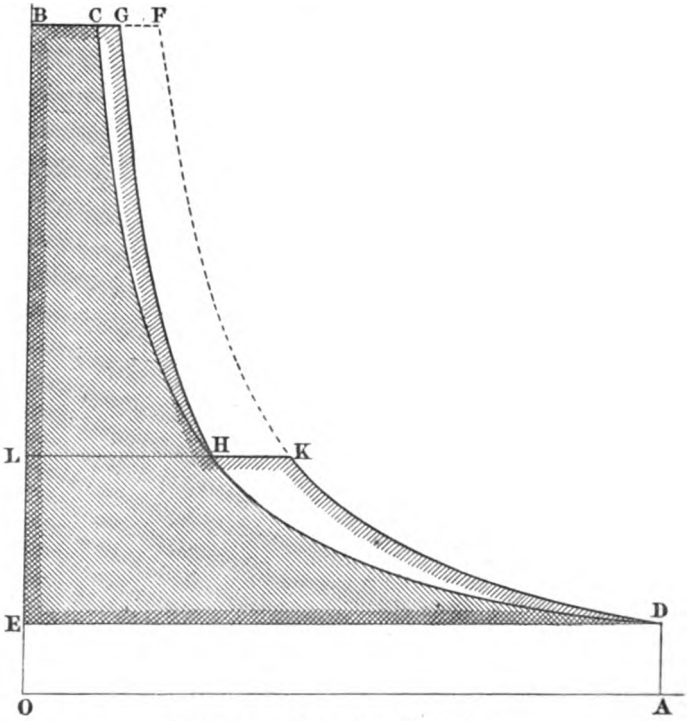
that the result is partly deceptive, the cooling going on after the air is completely compressed, so that the compression curve is hardly so much flattened as might be expected from the temperature at which the air is delivered.

The only remaining means of reducing the loss of work by heating is to compress in two or more stages, and cool the air thoroughly between the stages. This intermediate cooling can be

Fig. 5.



ACTION OF A COMPOUND COMPRESSOR.

easily effected, the air being taken through tubular vessels presenting any amount of cooling surface that may be required.

In *Fig. 5*, E B C D is the diagram of isothermal compression as before. D F is an adiabatic, so that in single-stage compression, without cooling, C D F represents the work lost in useless heating. Now let it be supposed that the compression is effected in two stages. In the first stage, no cooling being assumed, the work lost will be the area H K D. But the air is then cooled to its

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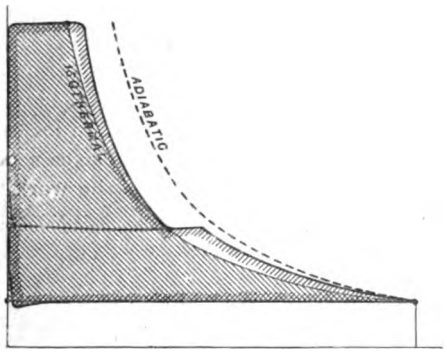
initial temperature, and the volume shrinks from L K to L H. H is a point on the isothermal D C. During the second stage H G is the adiabatic compression curve, and C G H the work wasted in heating the air. It can now be seen that the effect of the intermediate cooling is to reduce the work expended in compression by the area G F K H a very material quantity.

It is this stage-compression with intermediate cooling, and with spray injection also, which Professor Riedler has adopted in the new compressors for Paris, with marked increase of efficiency. *Fig. 6* shows an actual diagram from one of the Riedler com-

Fig. 6.



RIEDLER COMPRESSOR. REVOLUTIONS, 45; WASTED WORK, 12·07 PER CENT. OF USEFUL WORK.

pressors, and it will be seen that the excess compression is only 12·07 per cent., so that in this case η_2 has the high value 0·89.

In using air for transmitting power it is important, with a view of diminishing the size of the mains, to adopt high initial pressures, and it is the inefficiency of the compressing process in ordinary machines which has hitherto prevented the adoption of such pressures. Provided the efficiency of the compressors can be increased, much greater pressure loss can be permitted in the mains, and consequently, much smaller mains will suffice to transmit a given amount of power.

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PROFESSOR RIEDLER AND PROFESSOR GUTERMUTH'S EXPERIMENTS ON THE EFFICIENCY OF COMPRESSORS.

If, as above, $U_1 = \eta_1 U$ is the work expended in compression after deducting the friction of the mechanism, and

$$U_2 = 27{,}710 \log_e \frac{p_1}{p_a}$$

is the useful work done in compression, then

$$\eta_2 = U_2 / U_1 = U_2 / \eta_1 U$$

is a coefficient of efficiency of the compressing process, which includes both the waste of work in useless heating and any losses due to clearance, valve resistance, &c.

Professor Riedler has obtained a series of indicator diagrams from different compressor cylinders. On these he has drawn an ideal isothermal diagram without clearance or valve losses and for compression to the pressure in the main. The excess of area of the actual diagram over the ideal diagram is the work wasted in the compressing process, and from this η_2 is easily calculated. The following Table gives a series of such results:—

EFFICIENCY η_2 OF COMPRESSION.

Type of Compressor.	Pressure in Main, p_1. Atmos.	Lost Work in Per Cent. of Useful Work.	η_2
Colladon, St. Gothard	6	105·0	0·488
" "	6	92·0	0·521
Sturgeon	3	94·3	0·515
Colladon	4	38·15	0·722
Slide-Valve Compression	5	49·3	0·670
Paxman	..	42·7	0·701
Cockerill	6	40·2	0·713
Riedler Two-stage	6	12·07	0·892

The Table shows how very low is the efficiency of some of the older compressors. Even in the compressors in Paris with single-stage compression $\eta_2 = 0{\cdot}70$. Hence, if the friction of mechanism is taken account of, and η_1 is put at $0{\cdot}85$, the resultant efficiency is $0{\cdot}85 \times 0{\cdot}70 = 0{\cdot}595$, or less than six-tenths of the indicated work in the steam cylinder is usefully expended in compression. The Riedler two-stage compressor gives a much better result. Taking $\eta_1 = 0{\cdot}87$, its efficiency is $0{\cdot}77$.

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Professor Riedler has given some other figures, not based as the above are on the measurement of single diagrams, from which the efficiency of the Paris compressors can be calculated in a more trustworthy way. The following data are given as the result of a series of experiments with each compressor:—

Type of Compressors.	For each Indicated Steam HP.	
	Cubic Feet of Air at Atmospheric Pressure compressed per Hour.	Pressure in Main.
		Lbs. Per Sq. Inch Absolute.
Paxman machine (Sturgeon compressors) .	264·9	102·9
Cockerill machine (Dubois Francois compressors. . . . .)	300·2	102·9
Riedler Machine (Two-stage compressors) .	367·4	102·9

From these figures the following are calculated:—

—	Steam Work per Hour in Foot-lbs.	Weight of Air Compressed in Lbs.	Steam Work per Lb. of Air, =U.	Calculated Work per lb. for Isothermal Compression, U_2.	$\eta_1 \eta_2 = \frac{U_2}{U}$	η_1	η_2
Paxman . .	1,980,000	20·24	97,830	53,920	0·551	0·85	0·648
Cockerill .	..	22·94	86,340	..	0·624	0·85	0·735
Riedler . .	..	28·06	70,550	..	0·764	0·87	0·898

These results agree well with those obtained above in a different way.

Action of the Air Motors.

An air-motor is simply a reversed air-compressor. Hitherto the conditions of efficiency in air-motors have received very little attention. In Paris many of those used are of small size, and in these a good efficiency is not to be expected. The best results have been obtained thus far by adapting old steam-engines to work as air-motors, and this can be done at very little trouble. It is specially desirable that in an air-motor the cylinder clearance should be small or the compression sufficient. Probably the greatest source of avoidable waste in air-motors has been leakage at the piston. In a steam-engine, the condensation

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on the cylinder wall helps to render the piston tight. In an ordinary air-engine the cylinder surface is more or less dry, and the waste with air from leakage at even small apertures is very great.

A considerable economy can be secured by reheating the air in a simple form of stove before admitting it to the engine. At first sight this seems a complication likely to involve as much trouble as a steam boiler. That, however, is not at all the case. The reheating appliances are extremely simple, there is no risk of explosion, and the amount of heat which it is desirable to give to the air is insignificant compared with that required in raising steam. Professor Riedler tried an old 80-HP. steam-engine in Paris which had been adapted to work as an air-motor, and which was actually giving 72 indicated HP. with compressed air at 5½ atmospheres pressure. It was using about 31,000 cubic feet (reckoned at atmospheric pressure) or about 2,376 pounds of air per hour. This air was heated to a temperature of about 300° Fahrenheit by the expenditure of only 15 pounds of coke per hour. On a favourable assumption a steam-engine working to the same power would have required ten times this consumption of fuel at least. Reheating the air has the practical advantage of raising the temperature of exhaust of the motor, and for the amount of heat supplied the economy realized in the weight of air used is surprising. The reason of this is that the heat supplied to the air is used nearly five times as efficiently as an equal amount of heat employed in generating steam.

In certain cases the air-motor cylinder has been jacketed by hot air. This increases again the amount of work obtained per pound of air used. It can hardly be considered a thermodynamically advantageous process, but it may have advantages practically in raising the exhaust temperature. Lately in some cases water has been injected in small quantity into the air while passing through the re-heating stove. This passes into the engine as steam. It condenses during the expansion, yielding latent heat to the air, and thus raising the temperature of exhaust. Whether it is advisable from a purely thermodynamic point of view may be doubted, but it seems to have practical advantages possibly in lubricating the cylinder and preventing leakage. When steam is employed in this way the expansion curve rises above the adiabatic and becomes nearly an isothermal. The steam may amount to about 5 per cent. of the weight of air used.

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Useful work done by an Air-Motor.

Let the air be delivered from the main to the air-motor at the pressure P_2 in lbs. per square foot, or p_2 in lbs. per square inch. First let it be supposed that the air is used in the motor cold, its temperature being taken at 60° Fahrenheit and its volume in cubic feet per lb. being V_2. Expanded adiabatically in an engine down to atmospheric pressure, p_a, the work done would be in foot-lbs. per lb. of air.

$$U_3 = \frac{\gamma}{\gamma - 1} P_2 V_2 \left[1 - \left(\frac{p_a}{p_2} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

$$= 95{,}600 \left[1 - \left(\frac{p_a}{p_2} \right)^{0{\cdot}29} \right] \quad . \quad . \quad . \quad . \quad (16)$$

The actual work obtained in any given motor using air cold will be less than this in consequence of incomplete expansion, valve resistance, clearance, leakage and other losses. Let the actual work shown on the indicator diagram of the air-motor be U_4. Then if

$$U_4 = \eta_3 U_3,$$

η_3 is the efficiency with which the fluid is used in the particular air-motor, a coefficient which must be determined by experiment.

2nd. Let it be supposed that the air, arriving in the main with the temperature T_2 (absolute), is reheated to a temperature T_3 before being used in the motor. As it is reheated at constant pressure, the amount of heat to be given to each lb. of air is 183 $(T_3 - T_2)$ foot-lbs., or 0·2375 $(T_3 - T_2)$ thermal units. Then the work of adiabatic expansion from a pressure p_2 to atmospheric pressure p_a will be—

$$U'_3 = \frac{\gamma}{\gamma - 1} P_2 V_2 \frac{T_3}{T_2} \left[1 - \left(\frac{p_a}{p_2} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

$$= 95{,}600 \frac{T_3}{T_2} \left[1 - \left(\frac{p_a}{p_2} \right)^{0{\cdot}29} \right] \quad . \quad . \quad . \quad . \quad (17)$$

Generally the work shown by the indicator diagram of any engine will be less than this, for the causes mentioned above, and if η_3 is the efficiency with which the motor uses the fluid, the indicated work will be—

$$U'_4 = \eta_3 U'_3$$

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There is no reason for expecting η_3 to be different in this case from what it was in the previous one, unless hot-air jacketing, or steam injection, is used. In that case η_3 will be larger, and may be taken to include the additional work due to heat supplied during the stroke.

There is yet one more source of loss in the motor, the friction of the mechanism. If η_4 is the efficiency of the mechanism, then—

$$U_5 = \eta_4 U_4 \text{ or } \eta_4 U'_4$$

is the effective or brake work of the motor per lb. of air used.

Professor Riedler and Professor Gutermuth's Experiments on Air-Motors.—In the following Tables some of the experiments are quoted, together with the work per lb. of air, and the values of η_3 and η_4. When Professor Riedler does not give the indicated, but only the brake, HP. of the motor, it will be assumed that $\eta_4 = 0{\cdot}85$ in order to calculate a probable value of η_3.

It will be seen that in the older small motors the efficiency with which the fluid is used ranges from 0·37 to 0·44, which perhaps, considering the kind of motor, is a good result. In the later machines, arranged to work expansively, the efficiency ranges from 0·58 to 0·87, results remarkably good for motors so small. The coefficients are rather higher with reheated air, showing that the work done is increased even in a rather higher ratio than T_3/T_2.

Some other experiments on small motors may be passed over in order to consider some experiments on an old Farcot steam-engine, with Corliss valves, which had been converted for use as an air-motor.

This engine was nominally of 80 HP., and worked at 72 indicated HP. in the trials. In all cases the air was reheated before use to about 300° Fahrenheit. The cylinder was also jacketed by the hot air on its way to the cylinder-chest.

The efficiency is therefore 0·81, an extremely good result.

Of all the work obtainable by the expansion of 1 lb. of air received at 95·5 lbs. per square inch, and at a temperature of 300° Fahrenheit, four-fifths is obtained as effective work on the brake. However, part of this work recovered is borrowed from the hot air before admission to the cylinder and given back to it by the jacket. That the jacket considerably affected the working during expansion is shown by the temperature during exhaust.

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Small Rotating Air-Motors.

Nominal Size.	Revolutions per Minute.	Brake HP.	Temperature of the Air.		Initial Pressure. Lbs. per Square Inch Absolute.	Air used in Cubic Feet per Brake HP. per Hour.	Air used in Lbs. per Brake HP. per Hour.	Effective Work in Foot-Lbs. of 1 Lb. of Air $=U_5$.	Calculated Work of 1 Lb. of Air Expanded Adiabatically $=U_3$.	$\frac{U_5}{U_3} = \eta_3 \eta_4$.	Assumed η_4.	η_3.
			At Admission.	At Exhaust.								
HP.			Fahrenheit	Fahrenheit								
					Old Motors without Expansion.							
½	234	0·506	59	0	73·5	2,330	177·7	11,140	35,670	0·312	0·85	0·368
1	187	1·08	59	5	73·5	1,946	148·5	13,340	35,670	0·374	0·85	0·441
½	241	0·610	122	..	73·5	1,671	127·5	15·530	45,100	0·344	0·85	0·405
1	230	1·42	140	74	73·5	1,625	124·0	15,970	46,500	0·343	0·85	0·404
					Newer Motors with Expansion.							
1	221	1·24	60	−33	73·5	1,470	112·2	17,650	35,670	0·495	0·85	0·583
1	207	1·18	59	−44	73·5	1,286	98·2	20,170	35,670	0·565	0·85	0·665
2	200	2·30	68	−54	73·5	1,060	80·9	24,470	36,210	0·676	0·85	0·796
1	210	1·20	158	38	73·5	961	73·3	27,020	42,380	0·638	0·85	0·751
2	235	2·72	158	..	73·5	848	64·7	30,610	42,380	0·722	0·85	0·850
2	241	3·22	140	28	73·5	848	64·7	30,610	41,150	0·744	0·85	0·876

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TRIALS WITH AN 80-HP. FABCOT STEAM-ENGINE USED AS AN AIR-MOTOR.

Initial Pressure. Lbs. per Square Inch Absolute.	Indicated HP.	Temperature of the Air.		Air Used in Cubic Feet per Hour.		Lbs. of Air per Hour.		Indicated Work per Lb. of Air $=U_4$.	Brake Work per Lb of Air $=U_5$.	Work per Lb. of Air Expanded Adiabatically $=U_3^1$.	$\frac{U_5}{U_4}=\eta_4$.	$\frac{U_4^1}{U_3^1}=\eta_3$.
		Admission.	Exhaust.	Per Indicated HP.	Per Brake HP.	Per Indicated HP.	Per Brake HP.					
95·5	72·3	264	70	469	517	35·7	39·5	55,460	50,130	62,120	0·90	0·89
95·5	72·3	305	84	437	475	33·3	36·2	59,460	54,700	65,630	0·92	0·90
95·5	72·3	320	95	425	465	32·4	35·5	61,120	55,770	66,920	0·91	0·91
95·5	65·0	338	120	438	477	33·5	36·4	59,100	54,400	68,470	0·92	0·87
										Mean . .	0·91	0·89

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The following Table gives the temperatures the air would have reached by adiabatic expansion, and the actual temperatures of the exhaust in the experiments above :—

Initial Temperature.		Final Temperature for Adiabatic Expansion.		Actual Final Temperature Fahrenheit.	Increase of Temperature of Exhaust due to Jacket.
Fahrenheit.	Absolute.	Fahrenheit.	Absolute.		
264	725	−75	386	+70	145
305	766	−53	408	+84	137
320	781	−45	416	+95	140
338	799	−35	426	+120	155

Practical Calculations on the Distribution of Power by Compressed Air.

It will be convenient first to give a summary of the formulas required in settling a system of compressed-air distribution, and afterwards to discuss some special cases.

Let P_a be the pressure in lbs. per square foot, p_a the pressure in lbs. per square inch, V_a the volume of a lb. in cubic feet, T_a the absolute temperature of air admitted from the atmosphere to the compressor.

P_1, p_1, V_1, T_1 the same quantities for air discharged from the compressor into the main.

P_2, p_2, V_2, T_2 the same quantities for air arriving at the point of consumption in the main.

U = indicated work done by the steam on the piston of the compressor reckoned in HP.

$U_1 = \eta_1 U$ = corresponding indicated work in the compressor cylinder.

$U_2 = \eta_2 U_1$ = useful work of compression, or work of isothermal compression from p_a to p_1.

U_3 = available work of air arriving at the motor, or work of adiabatic expansion from p_2 to p_a.

$U_4 = \eta_3 U_3$ = indicated power of the air-motor.

$U_5 = \eta_4 U_4$ = effective or brake work of the air-motor.

Taking $P_a = 2116 \cdot 3$, $p_a = 14 \cdot 7$, $V_a = 13 \cdot 09$, $T_a = 621°$.

$$P_a V_a = 27{,}710 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If W foot-lbs. of air are compressed per second by U horse-power in the steam cylinder corresponding to U_1 indicated horse-power

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in the compressor cylinder, then, allowing both for friction of mechanism and clearance, leakage, and other losses in compression—

$$550\,\eta_1\,\eta_2\,U = 27{,}710\,W \log_e \frac{p_1}{p_a}$$

$$W = \frac{\eta_1\,\eta_2\,U}{50{\cdot}4 \log_e \frac{p_1}{p_a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

When by conduction in the main the air is at its initial temperature T_a—

$$P_1 V_1 = 27{,}710$$
$$p_1 V_1 = 192{\cdot}3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If v_1 is the initial velocity of the air in the main, the diameter of which in feet is d—

$$\frac{\pi}{4} d^2 v_1 = W V_1 = 192{\cdot}3\,W / p_1$$

$$d = 15{\cdot}64 \sqrt{\frac{W}{p_1 v_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The pressure falls in a main of length l in feet from p_1 to p_2, the amount being given by the equation—

$$\frac{p_2}{p_1} = \sqrt{\left\{1 - \frac{v_1^2\,l}{74{,}300{,}000\,d}\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The available work of the air arriving at the motor with the pressure p_2 at atmospheric temperature T_a is, if it is used without reheating, in HP.—

$$U_3 = \frac{95{,}600\,W}{550}\left[1 - \left(\frac{p_a}{p_2}\right)^{0{\cdot}29}\right] \quad . \quad . \quad .$$

$$= 173{\cdot}5\,W\left[1 - \left(\frac{}{p_2}\right)^{0{\cdot}29}\right] \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If reheated to T_3 before admission to the motor—

$$U'_3 = 173{\cdot}5\,W \frac{T_3}{T_a}\left[1 - \left(\frac{p_a}{p_2}\right)^{0{\cdot}29}\right] \quad . \quad . \quad . \quad . \quad (7)$$

Indicated work of motor $= U_4 = \eta_3\,U_3 \quad . \quad . \quad . \quad (8)$

Brake or effective work of motor $= U_5 = \eta_4\,U_4 \quad . \quad (9)$

Values assumed for the Coefficients of Efficiency.—It appears that the efficiency of the mechanism of compressors is from 0·85 to 0·87.

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In the following calculations it will be assumed that $\eta_1 = 0{\cdot}85$. As to the efficiency of the process of compression, this varies greatly with the type of compressor. In some of the older single-stage compressors it is as low as $0{\cdot}5$. But taking the best of those tried by Professor Riedler and slightly rounding off the values—

For single-stage compressors . . . . $\eta_2 = 0{\cdot}7$
„ two-stage „ . . . . $\eta_2 = 0{\cdot}9$

The loss in the main must be calculated for each special case.

For the air-motors, as it is not intended to discuss the use of air on a small scale, it will be assumed that $\eta_3 = 0{\cdot}85$ and $\eta_4 = 0{\cdot}9$. These values are slightly below those obtained in the experiments, and the results should therefore be such as are practically realizable in ordinary work.

Case I.—10,000 HP. is to be transmitted a distance of 2 miles. Taking $\eta_1 = 0{\cdot}85$ and $\eta_2 = 0{\cdot}9$ (two-stage compression) the useful work of compression will be 7,650 HP. Now, let the air be compressed to 4, 8, and 12 atmospheres on the gauge, then the weight of air compressed will be as follows:—

Case I.	Initial Gauge Pressure. Atmospheres.	Initial Pressure. Lbs. per Square Inch Absolute.	$\frac{p_1}{p_0}$	Weight of Air Compressed in Lbs. per Second = W.
a	4	73·5	5	94·54
b	8	132·3	9	69·10
c	12	191·1	13	59·17

To ascertain suitable diameters for the main, let initial velocities of 30, 50, and 75 feet per second be assumed. For these velocities, and in the cases described, the diameters required will be as follows:—

Case I.	Initial Pressure. Lbs. per Square Inch Absolute.	Initial Velocity in the Main. Feet per Second.	Diameter of Main.	
			In Feet.	In Inches.
a	73·5	30	3·23	39
		50	2·50	30
		75	2·05	25
b	132·3	30	2·06	25
		50	1·60	19
		75	1·31	16
c	191·1	30	1·59	19
		50	1·23	15
		75	1·01	12

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None of these mains are impracticable in size, and for the higher pressures and velocities they are surprisingly small, considering that they are shown to be capable of transmitting 10,000 indicated steam HP. a distance of 2 miles. It remains to examine whether the loss of pressure is serious.

Case I.	Initial Pressure. Lbs. per Square Inch Absolute p_1.	Initial Velocity in the Main. Feet per Second.	Diameter of the Main in Feet.	Terminal Pressure in Lbs. per Square Inch p_2.	Loss of Pressure in per cent. of Initial Pressure.
a	73·5	30	3·23	72·0	2·0
		50	2·50	68·0	7·4
		75	2·05	57·3	22·0
b	132·3	30	2·06	128·3	3·0
		50	1·60	116·5	11·9
		75	1·31	82·3	37·8
c	191·1	30	1·59	183·4	4·0
		50	1·23	161·1	15·7
		75	1·01	86·4	54·8

None of these losses would render the utilization of the power impossible, and it is only at the highest pressures and velocities that the fall of pressure is serious.

Lastly, the power developed at the air-motor due to 10,000 indicated steam HP. in the compressor has to be calculated. The air being delivered at a distance of 2 miles, and used cold, the HP. obtained will be as follows :—

Case I.	Initial Pressure. Lbs. per Square Inch Absolute.	Terminal Pressure in the Main. Lbs. per Square Inch Absolute.	Initial Velocity in the Main. Feet per Second.	Indicated HP. of Air-Motor.	Brake or Effective HP. of Air-Motor.
a	73·5	72·0	30	5,146	4,631
		68·0	50	4,998	4,498
		57·3	75	4,546	4,091
b	132·3	128·3	30	4,755	4,279
		116·5	50	4,600	4,140
		82·3	75	4,007	3,606
c	191·1	183·4	30	4,529	4,076
		161·1	50	4,369	3,932
		86·4	75	3,504	3,154

It is very striking how little the efficiency is affected by considerable changes in the initial pressure and velocity in the mains; with the exception of two cases, for 10,000 steam indicated HP.

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expended at the compressor there is obtained from 4,400 to 5,100 indicated HP. at the air-motor. That is to say, the efficiency of the whole arrangement, compressor, main, and air-motor, when the air is used cold, ranges from 44 to 51 per cent., and that with mains of quite moderate size.

If the advantage of reheating at the motor is resorted to, which in no case involves any great additional trouble, and which from the small amount of fuel required can often be carried out with very little additional expense, the HP. obtained will be as follows:—Let it be supposed that the air arriving at the motor at 60° Fahrenheit is reheated to 300° Fahrenheit, as in the case of the Farcot steam-engine, details of which are given above. Then—

$$\frac{T_3}{T_e} = \frac{761}{521} = 1{\cdot}46$$

Case I.	Initial Pressure. Lbs. per Square Inch.	Terminal Pressure. Lbs. per Square Inch.	Initial Velocity in the Main. Feet per Second.	Indicated HP. of Motor.	Brake HP. of Motor.
a	73·5	72·0	30	7,511	6,761
		68·0	50	7,297	6,567
		57·3	75	6,638	5,973
b	132·3	128·3	30	6,942	6,248
		116·5	50	6,716	6,045
		82·3	75	5,850	5,265
c	191·1	183·4	30	6,612	5,951
		161·1	50	6,380	5,741
		86·4	75	5,116	4,605

Here again, excepting two cases, the efficiency reckoned on the indicated power is from 64 to 75 per cent., neglecting the cost of the fuel for reheating.

CASE II.—A long-distance transmission may now be discussed. Suppose, as before, that 10,000 indicated HP. is developed in the steam-cylinders of the compressors, and is to be transmitted a distance of 20 miles. Taking the same pressures as before, the calculations of the weight of air compressed need not be repeated. The initial velocities previously assumed will, however, be excessive, because the velocity in the main increases as the pressure falls, and in this case, as the fall will be considerable, the terminal velocities are much greater than the initial velocities. Initial velocities of 20, 35, and 50 feet per second will be assumed.

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Case II.	Initial Pressure. Lbs. per Square Inch Absolute.	Initial Velocity. Feet per Second.	Diameter of Main in Feet.	Diameter of Main in Inches.
d	73·5	20	3·96	47·5
		35	2·99	35·9
		50	2·51	30·1
e	132·3	20	2·53	30·4
		35	1·91	22·9
		50	1·60	19·2
f	191·1	20	1·95	23·4
		35	1·47	17·6
		50	1·23	14·8

None of these mains are impracticable in size. The following Table gives the calculation of the pressure loss:—

Case II.	Initial Pressure.	Initial Velocity.	Diameter of Main in Feet.	Terminal Pressure. Lbs. per Square Inch.	Loss of Pressure in per cent. of Initial Pressure.
d.	73·5	20	3·96	68·0	7·4
		35	2·99	47·6	35·3
		50	2·51	Impossible.	..
e.	132·3	20	2·53	116·5	11·9
		35	1·91	12·6	90·4
		50	1·60	Impossible.	..
f.	191·1	20	1·95	160·8	15·8
		35	1·47	Impossible.	..
		50	1·23	Impossible.	..

It turns out on calculation that some of the cases assumed are impossible. That is, the whole initial pressure is insufficient to give the assumed initial velocity. In one other case the 1·91 foot main with a velocity of 35 feet, the loss of pressure in the main is impracticably large. There remain, however, four cases in which neither the size of main nor the loss of pressure in a transmission to a distance of 20 miles is such as to render the transmission impracticable. In three cases the loss is remarkably small, and the terminal pressure quite suitable for application. For instance, it appears that the air compressed by 10,000 HP. to 132·3 lbs. per square inch can be transmitted to a distance of 20 miles in a 30-inch main with a loss of pressure of only 12 per cent.

The power delivered at a distance of 20 miles by air-motors

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using the compressed-air can now be calculated. If the air is used cold the power obtained will be as follows:—

Case II.	Initial Pressure. Lbs. per Square Inch Absolute.	Terminal Pressure. Lbs. per Square Inch Absolute.	Initial Velocity in the Main. Feet per Second.	Indicated HP. of Motor.	Brake or Effective HP. of Motor.
d	73·5	68·0	20	4,989	4,490
		47·6	35	4,017	3,615
e.	132·3	116·5	20	4,598	4,138
f.	191·1	160·8	20	4,365	3,928

If the air is reheated to 300° Fahrenheit as assumed in the previous case—

Case II.	Initial Pressure. Lbs. per Square Inch.	Terminal Pressure. Lbs. per Square Inch.	Initial Velocity in Main. Feet per Second.	Indicated HP. of Motor.	Brake or Effective HP. of Motor.
d	73·5	68·0	30	7,284	6,554
		47·6	35	5,865	5,278
e.	132·3	116·5	20	6,713	6,041
f.	191·1	160·8	20	6,373	5,735

Here the efficiency of the whole arrangement—calculated on the indicated power, the air being delivered at a distance of 20 miles, and including all losses—is 40 to 50 per cent. if the air is used cold, and 59 to 73 per cent. if the air is reheated. The results are based absolutely on efficiencies already obtained in similar cases, and the sole loss neglected is possible leakage in the mains.

Fig. 7 is drawn to scale for Case II *e*. It is a diagram showing the relation of the work expended and useful work recovered when 10,000 HP. is transmitted 20 miles in a main 30 inches in diameter. It is drawn in the manner described in the Author's previous Paper. A E G B is the work expended in a two-stage compressor, compressing 1 lb. of air from 14·7 to 132·3 lbs. per square inch. By cooling in the mains the volume of the air shrinks from E G to E F. The frictional resistance reduces the pressure to 116·5 lbs. per square inch, when the air has the volume M K determined by the isothermal. The work done by an air-motor, using the air cold, is M K C A. If the air is reheated to

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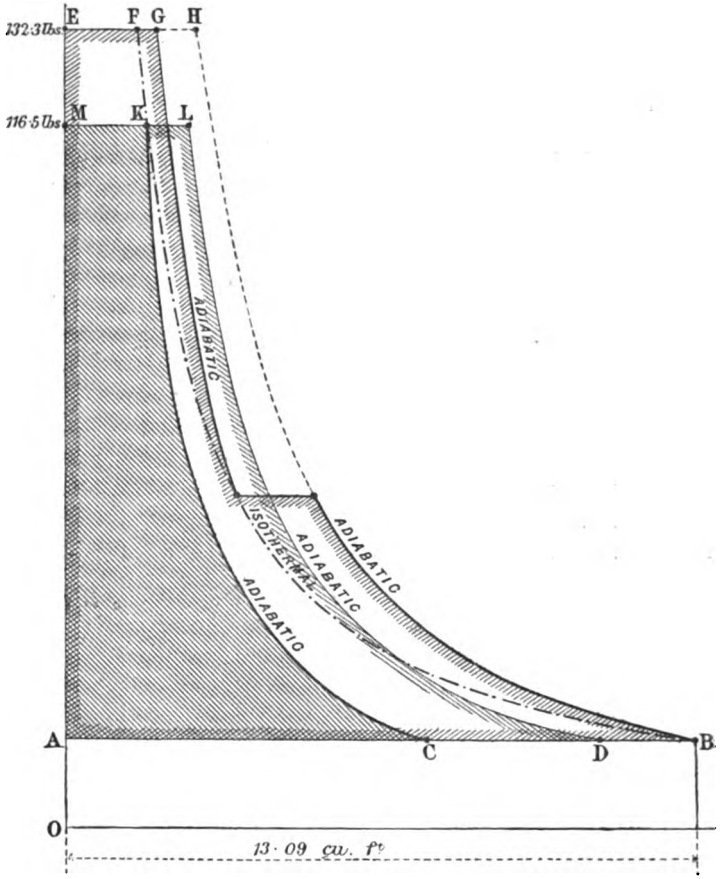
300° the volume expands from M K to M L (1·46 times). Then the work of the air-motor, using reheated air, is M L D A, and K L D C is the important gain of work due to reheating. Of course the

Fig. 7.



COMBINED ACTION OF COMPRESSOR MAIN AND MOTOR.

areas given by the diagram have to be multiplied by the efficiencies given above.

Figs. 1–7 in the text have been produced from materials supplied by the Author.

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(*Paper No. 2256.*)

"The Manufacture and Properties of Slag-Cement."

By GILBERT RICHARD REDGRAVE, Assoc. Inst. C.E.

IN a Paper by the late Major-General Scott and the Author, "On the Manufacture and Testing of Portland Cement,"[1] the chemistry of cement action was considered, and the opinions of foreign chemists were quoted, concerning the causes of hydraulicity in various lime compounds. The recent discovery of the possibility of producing a hydraulic cement from a mixture of blast-furnace slag and slaked lime, throws much light upon certain facts connected with the induration of cements; and in the present Paper an account is given of this material and the results of the tests to which it has been submitted.

Blast-furnace slag, though it varies greatly in composition, in accordance with the nature of the ores employed in the smelting of iron, contains generally all the chief ingredients found in Portland cement clinker, and on this account has often attracted the attention of cement-makers. In this country attempts have been made by Mr. F. Ransome, Mr. Charles Wood, and Mr. John Watson to turn this material to profitable account, but hitherto without much success. In Germany, less scrupulous manufacturers have availed themselves of slag in the adulteration of cement, for which purpose its great similarity with the "core," or hard particles present in genuine cement, renders it peculiarly suitable; while its detection by chemical analysis is a matter of considerable difficulty. The many failures experienced by previous inventors, coupled with its use for fraudulent purposes, have given slag a bad name among those who are engaged in dealing with cements.

The steps by which Messrs. Bosse and Wolters have succeeded in overcoming the difficulties encountered by previous inventors, are based upon the careful consideration of the chemical composition of the slag, and of the processes best calculated to bring the cementitious properties into action. All slags are not equally well adapted for the manufacture of cement; and those slags which disintegrate and fall into powder spontaneously, and which on this account have been preferred for purposes of adulteration, are wholly unfitted for cement making. Again,

[1] Minutes of Proceedings Inst. C.E., vol. lxii. p. 67.

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all slags highly charged with mineral oxides, compounds of sulphur, and large proportions of magnesia should at once be rejected. It is, however, easy to procure almost inexhaustible supplies of blast-furnace slag in which, while the percentage of lime, in proportion to the silica and alumina, is relatively high, it still falls far short of the amount of lime present in a good sample of Portland cement clinker. Care must also be taken that the silica and alumina bear a certain fixed ratio to the lime. By selecting a slag of this composition, which has been specially prepared, by incorporating with it a sufficient quantity of lime to ensure further chemical action, and by bringing about an extremely intimate mechanical mixture of the ingredients, the inventors of the slag-cement have produced a material resembling Portland cement in the extent and energy of its hydraulic action, and surpassing it in its sand-capacity, or power of binding together the aggregates employed in the preparation of mortar or concrete, as also in certain other respects. During their preliminary examination of upwards of one hundred varieties of slags, the inventors have encountered several peculiarities which are at present very difficult to explain, or to bring into accord with existing theories; and it is necessary, before any definite opinion can be pronounced respecting any given sample of slag, to submit it to careful analysis and to repeated tests. When once, however, a suitable specimen has been procured, the fluctuations in the daily composition of such a slag, obtained from a set of furnaces, have been found to be so trifling as to have little or no influence upon the quality of the resultant cement. In Appendix I analyses will be found giving the proportions of the three principal ingredients of the slag from the Carron works, which has been tested at intervals for a period extending over more than two years, and has yielded very uniform results. Appendix II contains the analyses of slags obtained from a large number of different sources.

The exact composition of the slag is, however, of much less importance than when an artificial compound of chalk and clay has to be prepared in the manufacture of Portland cement in the ordinary way. It has been ascertained that when the silicates have been fused together into a vitreous mass in the blast-furnace, comparatively large fluctuations, or at any rate the greatest differences encountered in the composition of the slags from the same furnace, have little or no effect upon the character and quality of the cement; and they can always be regulated to some extent by a trifling alteration in the percentage of added lime, or by suitable proportions of another slag. It has been definitely ascertained that

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no slag contains in itself a sufficient amount of lime to produce a cementitious action; or the lime already present, however large the proportion may be, has been so intimately combined with the silica and the alumina as to produce an almost wholly inert substance. A similar result is obtained during the calcination of Portland cement, when the heat is too great, and the clinker is partly fused or melted; in this case, either the whole of the lime becomes chemically combined with the silicates in such a way as to be incapable of further action when water is added, or the lime particles are so enclosed in, and surrounded by, the fused mass as to be rendered useless for the formation of fresh compounds. All previous experimenters have considered it necessary that a certain proportion of lime should be added to the slag; but most of the methods hitherto adopted for making this addition have been wrong in principle, and have been based upon the plan of recalcining the slag with the carbonate of lime to be so added. Not only does this system err in consequence of the cost it entails, but it likewise leads to the production of a less energetic cement, owing to the combinations which take place between the ready-formed silicates in the slag and the added quicklime or carbonate of lime at the high temperature necessary to burn the lime.

In the manufacture of the slag-cement as devised by Messrs. Bosse and Wolters, the requisite quantity of lime is added after it has been slaked, that is, in the condition of a very fine dry powder, and care is taken to exclude all unburnt particles and to employ only such lime as has been thoroughly burned, and becomes hydrated on the addition of water. Pure, or fat limes, in the act of slaking, "fall" into an extremely fine powder—in fact, the particles of slaked lime constitute a much finer powder than can be obtained by any mechanical means. White lime, such as is obtained from the upper chalk or from mountain limestone, yields the largest quantity of pure slaked lime, and is therefore preferred for slag-cement, although other more or less hydraulic limes, which slake and fall into a fine powder, can also be used. Previous to the mixing, the lime must be screened to exclude any coarse, unburnt and unslaked particles, and must be perfectly dried. The slag, on issuing from the furnace, is passed through a stream of water, by which means it is mechanically reduced to a spongy and readily-crushed material, which is already produced in considerable quantities under the name of "slag-sand." This slag-sand must be dried and ground to a fine powder by passing it between mill-stones, such as are used for grinding cement. The ground slag, with the requisite percentage of slaked lime,

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which is usually about 25 per cent. of the mixture, is then introduced into a machine, which has been termed by the inventors a "homogenizer." This consists of a 4½-foot metal drum or cylinder, partly filled with iron or steel balls from 1 to 2 inches in diameter. The cylinder is made to revolve slowly on its axis; and in consequence of the crushing and pounding action and the friction between the metal balls, as also the very complete intermixture of the contents caused by the rotary movement, the particles of lime and slag are most intimately united, and reduced to a smooth, silky powder, resembling to the touch the finest flour. The apparatus is both a mixer and a disintegrator; and it does this work at a very small cost. After remaining in the machine for about an hour, the charge may be withdrawn; and the slag-cement is then ready for use.

It is absolutely necessary, in order to obtain good results, that cements, of which slag forms the basis, should be very finely ground. There should be no residue on a sieve of seventy-five meshes to the inch, and not more than 15 to 20 per cent. on a sieve of one hundred and eighty meshes to the inch linear. This extreme degree of fineness can, however, be readily reached, as slag-sand is easy to grind, and the lime is already obtained of the required fineness in the act of slaking. The whole process of manufacture is indeed an exceedingly simple one, involving only the careful burning and slaking of the lime, the drying and grinding of the slag, and the reduction of the ingredients to an impalpable powder; while, as contrasted with the preparation of Portland cement, with the many dangers which may arise from errors in the first mixture, from imperfect calcination, and from careless grinding, the chances of failure are relatively small. It is always possible to obtain unlimited supplies of suitable lime; and slag, which is often regarded as a nuisance, is now produced in profusion in numerous localities; and when once a particular description of slag suitable for cement-making is found, there is little difficulty in procuring a continuous supply of sufficiently uniform composition. Trial samples of the cement can be produced in an hour; and any mistake in the quality of the slag can be readily rectified. Indeed experience has proved that more uniform samples of cement can be made from slag than from a mixture of chalk and clay. In its appearance, the slag-cement presents a striking contrast to Portland cement. In colour, it varies somewhat in accordance with the nature of the slag employed in its production, but it is always lighter than Portland cement in consequence of the presence of a considerable proportion of slaked lime. Owing partly to the very

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fine grinding, and partly to the lower specific gravity both of the slag and of the lime, the weight of the cement is much less than that of Portland, and seldom exceeds 75 lbs. per cubic foot, or say 94 lbs. per bushel. It is therefore a relatively bulky cement, and gives high results when tested with sand. When made up neat, it is more plastic and unctuous than Portland cement, and yields a richer and fatter mortar. In spite of its great fineness, specimens have been produced which give about the same results, when tested neat, as a good sample of Portland cement. It is, as a rule, a slow-setting cement, due probably to the fact that all the uncombined lime is already hydrated; but the chief dangerous elements are thereby eliminated, or at any rate minimized. In its chemical composition, the slag-cement differs widely from Portland cement, mainly in the higher percentage of alumina present and in its relatively low percentage of lime, which, unless a larger proportion than is actually required has been added for some special purpose, need not exceed 45 to 50 per cent., against from 58 to 62 per cent. generally present in Portland cement. The following is the composition of a good sample of slag-cement; and side by side with it, by way of comparison, are the quantities of the ingredients usually present in Portland cement:—

Ingredients.	Slag-Cement.	Portland.
Lime	46·53	60·59
Silica	24·10	22·23
Alumina	16·30	7·22
Oxide of Iron	0·93	4·32
Magnesia	2·08	1·10
Carbonic acid	0·65	0·80
Water (combined with lime)	6·45	1·05
Sulphuric acid	2·05	1·68
Insoluble and other matters	0·94	1·01
	100·03	100·00

The chemistry of the action of cements made from slag, though not in accordance with some of the theories propounded to explain the induration of Portland cement, is sufficiently intelligible. At very high temperatures in the blast furnace, compound silicates of lime, alumina, certain metallic oxides, and of the alkalies, are formed, and brought into a state of fusion. These

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silicates, when reduced mechanically to a fine state of division, have very little tendency to form fresh chemical compounds in the presence of water. The energetic action of certain cements depends either partially or entirely upon the formation of hydrated silicates, which rapidly solidify the water used in making the mortar, and are said to set. In all samples of Portland cement, there is a certain proportion of uncombined lime, which has either been present in excess of the requirements of the acids in the mixture, or which has become mechanically entangled in, or coated with, the vitreous silicates formed in the kiln. It is difficult to determine the exact proportion of this free lime; judging from the composition of the slag cement, it is probably larger than chemists have hitherto thought possible. When the Portland cement has been thoroughly purged, nearly all this free lime has become air-slaked, leaving, however, a small quantity of quicklime still protected from the access of moisture owing to its silicious envelope. When water is added to gauge the cement, a partial decomposition of the silicates in the slag appears to occur, and a mutual reaction between these but sparingly soluble silicates and the hydrate of lime, with which they are intimately mixed. It is almost impossible to account for the hydraulicity of the slag cement in any other way. The added lime, having been all slaked, can undergo no further chemical action when mixed with water; and the slag alone cannot set up any cement action in the presence of water. The mutual reaction of the slag and the calcic hydrate must, therefore, be due to a partial decomposition of the slag, and the immediate formation of fresh compounds of silica, lime and alumina, which compounds are not only capable of induration, but, in the act of setting, are able to unite very considerable quantities of aggregates in the form of mortar and concrete. If this view of the action of the silicates is correct, it would seem, either that in ordinary Portland cement the lime is present in dangerous abundance, or that in the slag-cement, owing to the extreme temperature attained in the blast furnace, different combinations of lime, alumina and silica are obtained, which, however, are of an equally fixed and stable character to those produced at relatively lower temperatures in the cement kiln. The behaviour of the mechanical mixture of slaked lime and very finely-divided silicates of lime and alumina, which constitutes the slag-cement, throws much doubt upon those theories of cement action which imply that, in Portland cement, the induration is caused by the hydration of ready-formed silicates, or that certain silicates produced by the action of heat in the kiln are, under the

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influence of water, recombined or altered into hydrated double silicates; for it is evident that, in the new cement, considerable quantities of uncombined lime are united to the silicates of alumina and other bases in the slag. The exact nature of this action has, however, not yet been satisfactorily explained.

It must be remembered that much depends upon the physical properties of the slags, apart from their chemical composition. Samples of slag, which appear by analysis to give very similar results, differ widely in their behaviour when made into cement. The physical tension which exists between the ultimate particles of the slag, which may be greatly altered by sudden or rapid cooling, either by means of the air-jet or by immersion in water, plays an important part in rendering the slag available for the manufacture of cement; indeed, without this sudden cooling even the best slags are valueless. That other considerations, besides purely chemical ones, influence the behaviour of the slag is shown by the following samples of slag-sand, which when analyzed gave almost identical results, but which, when treated in the same way and mixed with precisely the same amount of lime, gave widely different results. The composition of the slags was as follows:—

Ingredients.	A.	B.
Silica	24·10	23·22
Alumina	16·30	15·61
Lime	46·53	47·10
Oxide of iron. . . .	0·93	0·78
Soda, potash, &c.. . .	5·04	5·56
Carbonic acid . . .	0·65	0·85
Moisture	6·45	6·88
Total . .	100·00	100·00

Tested in the same way, the tensile strength was:—

1 Cement to 3 Sand.			
A.		B.	
7 Days.	28 Days.	7 Days.	28 Days.
Lbs. 326	Lbs. 431	Lbs. 150	Lbs. 208

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showing the former to be more than double the strength of the latter. Slags coming from the same district, and prepared in a similar way, do not, however, vary thus widely in their results; and the above disparity must be due to exceptional circumstances, which cannot at present be accounted for. One of the most important considerations with respect to a cement from an engineering point of view is its relative reliability and soundness; and this quality can only be judged by practical experience in actual work, or by a series of tests extending over a considerable period of time. As already seen, the process of manufacture entails fewer chances of errors and imperfections than does the production of Portland cement by any of the methods now practised. Injury could only result from subsequent disintegration, or slow decomposition of the silicates formed during the process of induration; and hitherto no such decomposition has been observed. The samples behave in the same way as Portland cement does; the tensile strength steadily improves, and more rapidly than Portland, until the maximum is attained; and no degradation, either of the neat cement, or of the same used in conjunction with sand, takes place. It would be difficult, indeed, to understand how such destructive changes could be brought about; for, in a good sample of slag-cement, the lime, which is in all cases the dangerous and mischievous element, is present in smaller quantities than in Portland cement. Slags rich in magnesia, another dangerous ingredient, would be rejected on analysis; and though considerably larger quantities of sulphates are found in certain slags than in ordinary samples of Portland cement, such slags may easily be avoided; yet it is still a moot point as to whether sulphuric acid within certain limits is an objectionable element in Portland cement. Specimens of slag cement, both neat and in combination with sand, have been submitted to the action of frost for several days, and have then been boiled for many hours, with less injury than Portland cement briquettes similarly treated; and pats of cement exposed to the weather, and to alternate heat and moisture, have remained wholly unchanged for many months. The cements made from slag differ from Portland cement in requiring no preliminary purging or storing; they may in fact be used at once on leaving the homogenizer. All cements of the Portland type continue to expand for some time after they are made, and in so doing increase slightly in weight, owing to the gradual absorption of moisture and carbonic acid from the atmosphere. Cements which have not been thus weathered are liable to expand, or blow, when used for mortar or for plastering; and it is customary to stipulate that freshly-made

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Portland cement shall not be used. Owing to the complete hydration of the lime in the slag-cement, and to the inert character of the silicates present in the slag, little or no change can take place in this material even when exposed to the atmosphere for a lengthened period. In fact, the only deterioration it can undergo consists in the gradual formation of carbonate of lime; but in consequence of the compactness of the powder, due to its extreme fineness, it is very slowly attacked by the carbonic acid, and it may be kept for months in sacks or even in paper bags without suffering much injury. The following experiments were undertaken to ascertain the amount of the loss in tensile strength due to protracted exposure to the atmosphere. Two samples tested with three parts of sand yielded :—

Age of Cement when Tested.	A.		B.	
	7 Days.	28 Days.	7 Days.	28 Days.
Fresh	254	340	240	320
Kept 15 months . .	243	321	225	303

or a deterioration of about 5 per cent. Slag-cement protected from actual moisture undergoes no change whatever; and this is a matter of great importance when cement has to be used at considerable distances from the place of manufacture, or when it is intended for exportation. It has been already pointed out that this material is slow-setting, the average time required for a good sample varying from two to five hours; and it differs but little in this respect from a dense hard-burned Portland cement. A few exceptional samples of slag-cement have been produced, which became indurated, whether as pats or test-briquettes, in little over an hour; but such cases are rare. Slow-setting cements will almost invariably be preferred, as they acquire the maximum strength much more rapidly than quick-setting cements. This is doubtless owing to the increased time afforded by the cements of the former kind for the operation of surface-attraction between the particles, the phenomena of induration being in all probability partly physical and partly chemical; whereas in the quick-setting cements, the chemical reaction is so rapid that no opportunity is afforded for the mechanical adjustment of the molecules. Slag-cement is, however, only slow for the first few hours of the setting process, and it speedily acquires great tensile

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strength, and when mixed with sand is often found to become, after three or four days, as strong as Portland cement in as many weeks. The extreme fineness of the slag-cement, and its toughness and plasticity give it important advantages, as compared with Portland cement, when used in work under water. These properties adapt it especially for tidal work; and it has been found that when thus employed, the water does not become so muddy as when Portland cement is used, which is a proof that the cement is less liable to be washed out of the mixture. The great fineness of the cement makes a closer and more plastic concrete, and one not so readily penetrated by the water. Pats or blocks placed in water directly they are made harden perfectly, and show little or no surface deterioration.

When slag-cement is allowed to harden entirely in the air, it behaves like any other slow-setting cement, the only thing needful to complete induration being to keep the materials damp during the whole of the time that the water required for the hydration is being combined. When used in thin layers for plastering, it is important that the surfaces to which it is to be applied should be well wetted; but no greater care is needed than when using a slow-setting sample of Portland cement. When employed for paving, slag-cement does not attain so hard a face as Portland cement, as might be expected from its inferior density; but, owing to its superior adhesive qualities it binds hard substances such as granite, quartz, &c., into a firmer mass than Portland cement does. A new method of testing hardness has recently been adopted in Germany, for which purpose test-blocks of a standard size and a given weight are pressed against a revolving disk. Each test-block has to be exposed to the same number of revolutions, at the same speed and under similar conditions; and the loss in weight in a stated time determines the relative durability and hardness of the various materials tested. Slag-cement has been submitted to this test; and, while the results with the neat cement were much lower than those in the case of Portland cement, the loss when tested with two to three parts of sand was almost exactly the same in the case of each kind of cement. This plan of testing is, however, still so little known and practised, that reliable data for comparison with Portland cement are not forthcoming. The specimens of Portland cement which show the greatest tensile strength when tested neat do not always give the best results when tested with sand. The object of all cement-testing is undoubtedly, firstly, the discovery of any latent defects in the cement, and secondly, to enable the observer to form an accurate estimate of

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the strength of the material as a binding agent in mortar and concrete. Unfortunately the system hitherto mainly adopted in this country is not well calculated to give prominence to some of the best qualities of the material. Few would dispute the axiom that the best and most economical cement, for practical purposes, would be that which was capable of uniting the largest proportion of aggregates into a firm and solid mass; and although, for saving of time and general facility of application, the neat cement-test may be mainly relied upon, this method of arriving at an estimate of the real quality of the material is fallacious and unsatisfactory.

In considering the sand capacity of any sample of cement, the degree of fineness to which it has been reduced is of paramount importance; and in the sand-test the slag-cement shows a marked superiority over Portland cement. A tensile strength of from 350 lbs. to 400 lbs. per square inch in twenty-eight days, with three parts of standard sand, would be the extreme limit attainable by the best English Portland cement, but this could only be secured by such careful sifting as to be practically out of the question. A sample of slag-cement with three parts of sand has been broken at 540 lbs. in twenty-eight days; and this cement had not been deprived of all particles rejected by a sieve of thirty-two thousand meshes to the square inch, as was the case with a specimen of the best Portland cement, which stood 371 lbs. on the square inch after twenty-eight days. It would be quite impossible, on the score of expense, to produce Portland cement of the degree of fineness attained in the ordinary course of manufacture in the case of slag-cement.

A few selected tests are given in a tabular form to indicate what may be expected from this new material (see Appendix III). They must not be regarded as showing the best that can be done with slag-cements; but they will be sufficient to prove that, in many respects, this material will compare favourably with Portland cement. In Appendix IV will be found the results of a series of tests of slag-cement, made by the Royal Testing Establishment at Berlin. This sample was prepared in the presence of the Author.

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APPENDIXES.

Appendix I.—Analyses of Blast-Furnace Slags from Carbon Works.

	Silica.	Alumina.	Lime.
Mean of 28 examples examined from May, 1887, to May, 1888	30·55	25·65	35·00
Mean of 25 examples examined from May, 1888, to May, 1889	29·97	24·14	34·89
Mean of 10 samples examined from May to October, 1889	30·47	20·21	37·44

Appendix II.—Analyses of Different English Slags.[1]

Locality.	Silica.	Alumina.	Lime.	Foreign M.
1. Staffordshire	41·99	23·27	31·62	3·21
2. South Wales	42·84	28·84	26·13	2·11
3. „ „	32·30	15·70	44·80	7·20
4. Yorkshire	39·47	23·66	32·12	4·75
5. Lancashire	33·49	10·12	46·97	8·54
6. Staffordshire	49·05	10·84	34·33	5·78
7. Warwickshire	41·30	16·20	40·80	2·70
8. „	36·30	13·86	30·49	9·76
9. Scottish	32·10	24·28	35·43	8·10
10. Nottinghamshire . . .	32·18	31·50	33·05	3·27
11. Lancashire	38·68	13·13	45·82	2·37
12. Cumberland	34·00	15·10	47·20	3·70
13. Derbyshire	39·24	23·04	32·06	5·66
14. „	40·00	11·50	40·60	7·90
15. Lincolnshire	32·86	21·88	40·34	6·12
16. „	31·37	19·69	40·23	8·71
17. Northamptonshire . . .	39·06	21·54	37·16	2·24
18. North Wales	31·28	12·41	46·10	10·21
19. Newcastle	26·37	14·42	48·84	10·07
20. „	34·15	16·68	43·39	5·78
21. „	31·05	23·15	36·51	9·29
22. Cleveland	32·15	17·53	45·50	4·82
23. „	35·45	21·55	33·70	9·30
24. „	29·89	26·13	34·35	8·63
25. „	30·98	28·03	33·33	7·60

[1] A great number of these are of no use for cement making.

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APPENDIX III.—SLAG-CEMENT. RESULTS OF TESTS IN LBS. PER SQUARE INCH.

These tests were made with briquettes of the same sectional area, broken in a double-lever testing machine. All samples had approximately the same fineness of between 10 to 15 per cent. residue on a 180 per inch sieve. Worthyfield standard testing sand was used for all sand-mortars. Sand briquettes were made with about 9¼ per cent., and neat tests with about 21 per cent. of water. All briquettes were hardened twenty-four hours in air and the remainder of the time in water.

Locality.	One Part Cement : Three Parts Sand.							Neat.		
	Days.				Months.			Days.		Months.
	2	4	7	28	3	6	9	7	28	3
South Wales .	..	..	306	350	441	..	..	582	698	715
Lancashire .	..	..	80	120	..	..	..	..	..	..
Staffordshire .	..	..	117	180	..	..	..	230	250	..
Cumberland .	..	..	80	160	..	..	..	..	..	..
North Wales .	..	..	108	137	..	..	..	285	315	..
Scotland . .	..	..	227	340	415	..	..	340	415	..
Lincolnshire .	..	..	280	372	390	409	..	522	585	..
Cleveland .	..	..	280	398	428	510	..	415	507	..
„ .	205	285	340	480	532	618	675	458	560	610
Newcastle .	..	..	235	350	407	480	..	430	498	..
„ .	..	..	298	420	455	471	..	560	700	..
Warwickshire	..	..	205	262	305	..	..	516	545	..
Somersetshire	..	..	208	371	434	431	..	451	582	601
Cleveland. .	185	250	325	415	480	505	..	402	485	..

APPENDIX IV.—INVESTIGATION CARRIED OUT BY THE ROYAL TESTING ESTABLISHMENT FOR BUILDING MATERIALS AT BERLIN.

Results of the examination of a parcel of cement forwarded on the 3rd December, 1886, marked "Sample of Cement," without further particulars as to locality. The tests were commenced on the 9th December, 1886, under the rotation number Spec. XVI, No. 4,764.

As a mean of three observations in each case :—	Kilogrammes.	Lbs. per Cubic Foot.
1 litre of the cement lightly filled = ...	1·042	65
„ „ shaked down = ...	1·611	100·5
„ normal sand = ...	1·640	102·3

The normal sand was obtained by the selection of the finest possible quartz sand, which was washed and dried. From it were removed all the coarse particles rejected by a sieve of sixty meshes to the square centimetre, and only the particles subsequently retained on a sieve of one hundred and twenty meshes per square centimetre were employed.

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The production of a suitable mortar needed 40 per cent. of water, 500 grammes of the cement being used. A slightly stiffer mortar required 36 per cent. of water; the temperature of the cement and the water being the same, and equal to that of the atmosphere of the laboratory, the rise of temperature on mixture was 0·7° Centigrade. It was made up into pats on glass, and set in 2¾ hours, the average temperature throughout the experiment being 22·5° Centigrade.

Tested with the sieve, the following results were obtained:—

5,000	meshes	per	square	centimetre,	14·0	per cent. residue.
900	,,	,,	,,		5·0	,, ,,
600	,,	,,	,,		1·0	,, ,,
324	,,	,,	,,		0·5	,, ,,
180	,,	,,	,,		0·0	,, ,,

The tests for expansion and contraction were carried out by means of ten pats of neat cement, made up on glass and roofing-tile, and trowelled to a thin edge. The pats remained twenty-four hours in air, and were then placed in water. They kept perfectly true and sharp-edged, and free from cracks. There was no expansion or contraction, and the cement adhered to the glass. When broken it presented a close even-grained and uniform fracture.

The briquettes employed to ascertain the tensile and compressive strength were made up on December 10, 1886, as follows:—

(*a*) The neat cement was mixed with 16½ per cent. of water.

(*b*) The sand briquettes were made of one part by weight of cement, three parts by weight of normal sand, and 7½ per cent. of water. The mixture was beaten into metal moulds placed on glass plates in the usual way.

The temperature of the air was 22·5 Centigrade.
,, ,, ,, water ,, 16·2 ,,
The moisture of the air was 68 per cent.

The tests set the first day in air, covered up with writing paper to avoid too rapid dessication; the remainder of the time they were in water. Taken from the water and tested they gave the following results:—

Mixture.	Tension.					Compression.					Proportion of Tensile to Compressive Strength.	
	Closeness after Filling	Tensile Strength after 7 Days.		Tensile Strength after 28 Days.		Closeness after Filling	Compressive Strength after 7 Days.		Compressive Strength after 28 Days.			
		German.	English.	German.	English.		German.	English.	German.	English.	7 Days.	28 Days.
		Kils. per sq. cm.	Lbs. per sq. in.	Kils. per sq. cm.	Lbs. per sq. in.		Kils. per sq. cm.	Lbs. per sq. in.	Kils. per sq. cm.	Lbs. per sq. in.		
1 to 0	2·113	45·50	647·0	48·65	692·0	..	..	..	..	..	..	..
1 to 3	2·261	30·03	427·0	35·78	509·0	2·262	237·3	3,376	300·1	4,269	1 to 7·902	1 to 8·337

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NEAT CEMENT.

No.	7 Days.		28 Days.		Remarks.
	German.	English.	German.	English.	
	Kils. per sq. cm.	Lbs. per sq. inch.	Kils. per sq. cm.	Lbs. per sq. inch.	
1	44·25	629	48·25	686	Made on metal plates, with 16½ per cent. of water.
2	45·50	642	45·75	651	
3	43·25	615	53·00	754	
4	48·00	683	49·00	697	
5	44·00	625	48·00	683	
6	46·50	653	48·50	694	
7	45·75	651	48·25	686	
8	44·25	629	52·50	746	
9	48·00	683	46·25	657	
10	45·50	647	47·00	668	
Total .	455·00	6,457	486·50	6,922	
Average	45·50	*646*	48·65	*692*	

ONE PART CEMENT AND THREE PARTS SAND.

No.	7 Days.		28 Days.		Remarks.
	German.	English.	German.	English.	
	Kils. per sq. cm.	Lbs. per sq. inch.	Kils. per sq. cm.	Lbs. per sq. inch.	
1	31·50	448	38·25	544	Made on non-absorbent plates, with 7½ per cent. of water.
2	30·00	427	35·00	498	
3	28·50	405	36·50	518	
4	31·50	448	37·75	536	
5	29·00	412	35·50	505	
6	31·00	440	34·50	490	
7	30·50	433	35·75	508	
8	31·50	448	34·50	505	
9	27·25	387	33·50	476	
10	30·00	430	36·50	519	
Total .	300·75	4,278	357·75	5,099	
Average	30·03	*427*	35·78	*509*	

The briquettes were for the first day in the air, and the remaining time in water.

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ONE PART CEMENT AND THREE PARTS SAND.

No.	7 Days.		28 Days.		Remarks.
	German.	English.	German.	English.	
	Kils. per sq. cm.	Lbs. per sq. inch.	Kils. per sq. cm.	Lbs. per sq. inch.	
1	229·6	..	287·8	..	Made on non-absorbent plates, mixed with 7½ per cent. water.
2	252·0	..	292·3	..	
3	237·4	..	305·8	..	
4	235·2	..	303·5	..	
5	233·0	..	292·3	..	
6	234·1	..	304·6	..	
7	229·6	..	291·2	..	
8	246·4	..	315·8	..	
9	230·7	..	292·3	..	
10	245·3	..	315·8	..	
Total .	2373·3	..	3001·4	..	
Average	237·3	*3,376*	300·1	*4,269*	

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(*Paper No. 2542.*)

"A Method of Constructing the Sub-Aqueous part of Piers and Breakwaters with Soft Un-set Concrete."[1]

By WILLIAM KIDD, Assoc. M. Inst. C.E.

THE method of construction described was adopted by the Author for a harbour at Skinningrove, on the Yorkshire coast, about 8 miles south of the mouth of the Tees. The sea bottom there consists of shale, 6 feet below low-water spring tides, covered with sand of varying thickness. The site is exposed from north-west round by north to east, the waves being from 15 to 18 feet in height during gales from these quarters. Only a small plant was available, precluding the adoption of large masses of concrete, either in bags, or in blocks. A former experience in the deposit of soft concrete in mass under water at Blyth Harbour,[2] though accomplished in a fully sheltered estuary, led the Author to adopt that method, with modifications to suit the altered conditions.

The pier was constructed in lengths of 20 feet, without staging. A 5-ton steam crane, advanced to the end of a completed length, commanded the next one. The sand was first removed by an 8-inch centrifugal pump with two 6-inch suction nozzles; one of these was connected with an india-rubber hose, and, being guided by a diver, cleared the sand from a space 25 feet long by 40 feet broad, laying bare the underlying shale; the other nozzle meanwhile sucked up water to keep the pump from choking.[3] The sand stood well at a steep angle under water at the sides of the excavated space; and, moreover, the concrete was deposited immediately the bottom was cleared. The freshly-mixed concrete was deposited from hopper boxes, holding 20 cubic feet, lowered by the crane, and directed by a diver, so as to make a "reef" over the entire excavated space, without any protection, and forming natural slopes at the sides of about 1 to 1.[4] It was levelled and trodden down by

[1] A general description of the Harbour Works, near Saltburn-by-the-Sea, appeared in *Engineering*, March 11, 1890, p. 317. That article included details of the properties and mode of manufacture of the Slag-Cement.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 302.

[3] The removal of sand cost 3*s*. 11·7*d*. per cubic yard.

[4] The slope on the harbour side was removed on the completion of the work.

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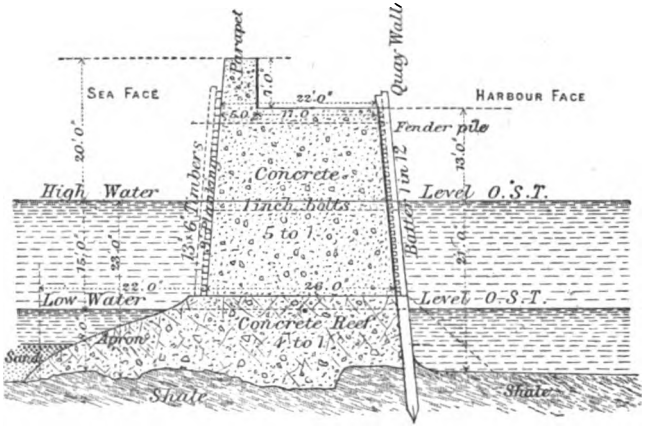
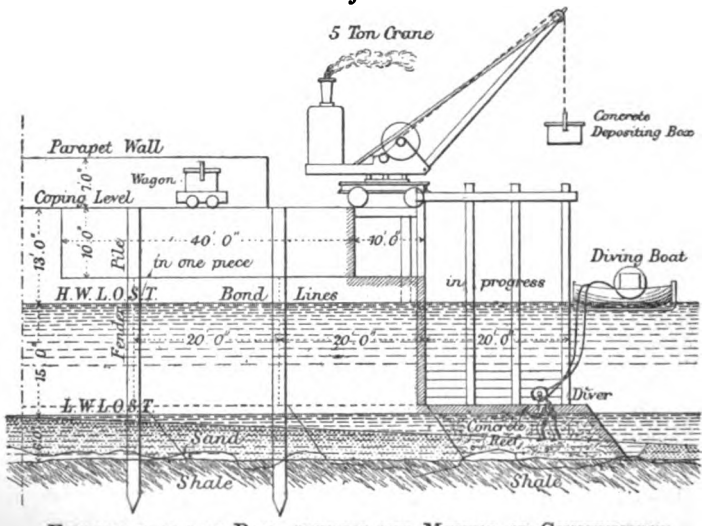
the diver, and carried up to 1 foot above L. W. O. S. T., or 7 feet

Fig. 1.



Section of the Pier.

Fig. 2.



Elevation of the Pier, showing the Method of Construction.

from the foundation. The timber framing for the superstructure was erected upon it after it had become hard. This concrete was

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composed of 2½ parts of broken slag, ½ of rough gravel, 1 of sand, and 1 of cement, measured separately. The formation of the "reef" was carried on continuously, from the first deposit of concrete, until the whole excavated space forming one length of foundation was covered, and raised above the level of the surrounding sand. It was then completed the following day, or as soon as the weather permitted. A length of about 300 lineal feet of the lower part of the North Pier has been executed in this manner, including also an apron along its seaward side.

The use of large bags or blocks is almost universal for the portions under water of the exposed parts of harbour works along the north-east coast; and apparently no attempt had been made to use concrete in mass exclusively for this purpose. A trial length, however, carried out as described, afforded satisfactory results; and experience during the subsequent progress of the work established the success of the system. As the progress of the under-water portion of such a structure is the measure of the speed of constructing the whole work, it was important to ascertain in what state of the sea the unprotected concrete could be deposited. In a favourable working year, 1890, the number of "working days," both in "reef" and superstructure, was one hundred and forty-four, a "working day" being one on which the waves did not exceed 4 feet in height. As the "reef" extends to only 6 feet below L. W. O. S. T., it is within the region of greatest scour during storms. Nevertheless, the sub-aqueous concrete was frequently deposited, and was but little disturbed when the waves were from 3 to 4 feet high; but with higher waves the concrete was more or less washed away. A "ground swell," however, was much more destructive; and the deposit of concrete in the "reef" was suspended during its prevalence. Although, on the coast at Skinningrove, the sea rises very rapidly in north and north-east gales, experience showed that, after being twelve hours in place, the concrete suffered practically no damage from a storm; and the loss of concrete during the progress of the work was trifling. Frequently waves from 10 to 15 feet high were washing over the "reef" twenty-four hours after deposit, without damaging it materially.

As divers are required for depositing large blocks or bags, and barges for the purpose have to be moored with precision, the Author has come to the conclusion that work can be carried on by this system under practically as severe conditions as bag or block work. In special cases, however, where speed of construction has been the first necessity, very heavy bags have been successfully

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deposited to form a strong, though rough base, under conditions which would render the deposit of soft unprotected concrete impossible; but, on the other hand, during working weather, the system of depositing soft concrete admits of very high speed being attained. An important objection to the deposit of soft concrete below water is that part of the fine cement, which is in suspension during the disturbance of the concrete while being manipulated, settles in the form of a creamy deposit termed "laitance," forming layers or pockets in the mass which never set. It was found, however, that as the concrete was unenclosed, the motion of the water at once carried away the suspended cement, and prevented its settlement on work. On careful inspection, the whole of the sub-aqueous concrete in the "reef" has been found to be sound and hard throughout; and, moreover, the heavy scour during storms to which, from its position at the toe of a vertical wall, it is subject, would have revealed any imperfections. Each length of foundation, weighing about 400 tons, is, in fact, a single solid mass, as proved by borings right through the "reef."

From the success of the system where the "reef" was deposited within the region of greatest scour near low-water level, the most difficult part of a sea structure, it may be safely assumed that the deposit of soft concrete can be successfully applied to many piers and breakwaters with deep-water foundations. The system is undoubtedly much more economical than either the bag or the block systems, as the average cost of the "reef" concrete amounted to 12*s.* 9*d.* per cubic yard.[1]

The Skinningrove Iron Company, the proprietors of the harbour, manufacture a hydraulic cement from Cleveland blast-furnace

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[1]

	Per Cubic Yard. s.	d.	Remarks.
Wages:—			
Labour	3	3	
Diving	0	10½	
Materials:—			
Cement at 20*s.* per ton	5	0	For Portland cement the price is 32*s.* per ton, adding 3*s.* to this item.
Broken slag	1	6½	or 62 per cent. of 2*s.* 6*d.*
Sand and gravel	0	8½	or 38 per cent. of 1*s.* 11*d.*
Coals and stores	0	3½	
Sundries	0	3½	
Depreciation of plant	0	3	
General Charges:—			
Proportion of engineering	0	6½	

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slag, which was accordingly used for the whole of the concrete in the works. (See Appendix.) Although this cement gave highly satisfactory results under water, the Author is of opinion that the same results would have ensued with good Portland cement. The experience obtained in this work shows that large masses of perfectly sound concrete *in situ* can be rapidly formed under water, in exposed situations, without special plant and without staging, at a very small cost.

The harbour works were successfully completed in 1891; and the Author has been the Engineer throughout.

The communication is accompanied by four photographs and a plate, from the latter of which the *Figs.* in the text have been prepared.

[APPENDIX.

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APPENDIX.

Concrete in the Superstructure.

The concrete used in the superstructure above the reef deposited out of water was composed of 3 parts broken slag, ½ of gravel, 1 of sand, and 1 of cement (see the Table below). All these materials were measured separately in a dry state before being mixed. Large lumps of slag were added to, and incorporated with, the concrete after it was deposited in place, to the extent of about one-sixth of the whole mass. The Author found in practice that with these proportions he obtained the utmost quantity of finished concrete—having a matrix consisting of equal parts of sand and cement—consistent with the making of perfectly solid work. The same proportions did not produce a concrete suitable for deposit below water, there being too much broken slag to admit of making solid work in places where the concrete could not be manipulated with a shovel after deposit.

The following data relating to this concrete were also obtained.

The materials in the above proportions when dry measured 5,431·69 cubic inches (see Table below). After being mixed and turned over three times dry, and three times after 394·27 cubic inches of water were added, they produced a finished block of concrete measuring 3,133 cubic inches, or 57·68 per cent. only of the bulk of the dry materials. While, in the dry materials, the proportion of all other materials to the cement is as 4½ to 1, in the finished block this propor-

Measurement of Mixed Materials in Concrete Test-Block as Completed.

Material.	Parts by measurement dry.	Total dry measurement.	Interstices to be deducted.	Net solid Material.	Per cent. of finished measurement.
	No.	Cubic Inches.	Cubic Inches.	Cubic Inches.	
Broken slag, largest pieces to pass through a 4-inch ring, smallest through a 1-inch ring.	3	2,962·74	1,458·70	1,504·04	48·0
Gravel, to pass through a ¾-inch ring.	½	493·79	160·37	333·42	10·7
Sand, coarse and containing small pea gravel . . .	1	987·58	236·35	751·23	24·0
Cement	1	987·58	144·78 (Shrinkage after wetting.)	842·80	26·9
Totals	5½	5,431·69	2,000·20	3,431·49	109·6
Deduct settlement after mixing				298·49	9·6
Net measurement of finished concrete block . .				3,133·00	100·0

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tion becomes 2·7 to 1; and the proportion of the finished concrete to the cement used is 3·2 to 1. The reduction in bulk, and the difference in the proportion of cement in the finished block, are chiefly due to the interstices in the principal components. These results illustrate the great difference in two concretes, both of which may be specified to be in the proportion of 4½ to 1, in one of which the materials are all measured together in a single gauge-box containing 4½ measures of the cement, and in the other where the materials are all measured separately, as in this case, and where the finer materials are largely absorbed to fill the interstices in the coarser materials. The preceding Table shows the proportions after allowing for the interstices.

The subjoined figures show the quantity of mortar (sand and cement) compared with the interstices:—

Mortar:—	Cubic Inches.
Total quantity cement, dry measure	987·58
which becomes reduced after wetting to	842·80
Deduct the interstices in the sand	236·35
	606·45
Add total sand (including interstices)	987·58
Total quantity of mortar	1,594·03

Interstices:—	Cubic Inches.
Interstices in slag	1,458·70
„ „ gravel	160·37
Total	1,619·07
Deduct solid gravel (which goes to fill them)	333·42
Total interstices to be filled with mortar	1,285·65
Surplus mortar is therefore	308·38

Tensile Strength of Concrete.

The tensile strength of the above concrete was tested by applying weights to the centre of a concrete beam, 5 feet long by 12 inches deep by 6 inches broad. At six months it was placed upon supports, 3 feet apart, and loaded over the central 12 inches of its length. The breaking load was 3 tons 12 cwt., or 1 cwt. per square inch of sectional area. The fracture showed the pieces of hard slag to be broken through equally with the matrix.

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(*Paper No. 2555.*)

"Irrigation in Southern California, with Special Reference to the Artesian Wells in San Bernardino County."

By WILLIAM FOX, M. Inst. C.E.

ORANGE-CULTURE has been carried on in California since the beginning of the present century, having been introduced by the Spanish mission-priests. Whether the first enterprises were accompanied by irrigation, the Author cannot say positively, but he has noticed in connection with several of the old mission buildings the remains of irrigation-ditches, and these missions were invariably situated at spots where water was easily available.

In the early part of 1890 the Author had occasion to visit several irrigation-systems in Southern California, and the following notes made during his journey are submitted in the hope that they may prove of interest.

QUANTITY OF WATER REQUIRED FOR IRRIGATION.

An important point to be considered is the acreage that a given quantity of water will irrigate. From April to November inclusive may be looked upon as the rainless season in Southern California. There may be years when rain falls within this period, but in considering the extent of land to be irrigated it is necessary to contemplate an extreme drought as the test of the value of the supply. This period may be taken at two hundred days.

The quantity of water required is influenced by the character of soil, the kind of crop it is proposed to grow, and the mode of applying the water. The soil varies from light sandy to strong loam, the latter requiring less water than the former but very careful handling and thorough cultivation after irrigation. The fruit crops, grown on irrigated land, consist of citrus and deciduous fruits, raisins and wine grapes, olives, figs and walnuts, as well as vegetables and alfalfa. The cost involved in constructing irrigation-works prevents any profit being made by growing grain crops. Citrus fruits require irrigation during the whole of the rainless

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season. One miner's inch[1] to 5 acres is commonly allowed for this crop in California, and even as much as 1 miner's inch to 3 acres is used in some instances. Deciduous fruits, such as peaches, prunes, and apricots, do not require so much water. Vines, when once established, are not watered after May or June, and figs, walnuts, &c., do not require much water after they are in full growth.

The old mode of irrigating in California is to run the water in ditches and flood the entire surface, which is only practicable with fairly level land and abundance of water. A more modern system for fruit culture consists in turning the water into basins made round the trees by throwing up a ridge to contain it until it has soaked down. The usual plan is to run two or three furrows along each side of a row of trees, and regulate the flow of water so that it will fill the furrows without overflowing or washing the soil. The water is brought to the furrows by means of a small flume or ditch intersecting them along the highest part of the tract under treatment.

A system of subsoil-irrigation has also to a limited extent been introduced, which consists of a series of concrete pipes laid in the ground deep enough to escape the cultivator. The water is allowed to flow from these pipes by means of a branch opposite every tree, regulated by a plug, being thus delivered where it will do most good, and avoiding to a great extent loss by surface evaporation. The Author understands that this system is not much followed on account of its cost, and its liability to get out of order through the pipes being choked by roots.

With any of these methods the land should invariably be cultivated after each irrigation.

The following represents the water-duty on several organizations in Southern California:—

Sweetwater (San Diego)	1	miner's inch	to	10	acres.
Gage-system (Riverside)	1	,,	,,	5	,,
Pomona (San Bernardino)	1	,,	,,	10	,,
Ontario	1	,,	,,	10	,,
Redlands	1	,,	,,	4	,,
Los Angelos	1	,,	,,	4	,,

It is the Author's opinion that 1 miner's inch to 10 acres, economically applied and with proper cultivation, will be sufficient to grow to advantage an average assortment of the crops men-

[1] A Californian miner's inch has been fixed by the courts, for legal purposes, at $\frac{1}{50}$th of a cubic foot per second, or nearly 11,000 gallons per day of twenty-four hours.

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tioned. He understands that with this amount, lands on the Sweetwater enterprise have realized £60 per acre, which had been selling for £20 per acre without water. Should it, however, be contemplated to grow only citrus fruits on any particular irrigation system, 1 miner's inch to 5 acres should be allowed.

One miner's inch to 10 acres for a period of two hundred days is equivalent to a depth of 10½ inches distributed on the surface. This is much less than is usually allowed for irrigation in Southern Europe, Egypt, or India, where the quantity distributed sometimes is as much as 60 inches in depth.

On the subject of rainfall in San Diego County, Southern California, Mr. W. H. Hall, State Engineer for California, in one of his reports on irrigation, says that precipitation is in a marked degree proportional to altitude.[1]

He divides the country into three belts, the first comprising all the mesas and valleys adjacent to the coast below an elevation of 1,000 feet. The rainfall in this belt he says is subject to great variation. The records, kept at San Diego from 1849 to 1860 by the United States War Department, and since 1871 by the Signal Service, show that for thirteen years out of twenty-three the rainfall was less than 10 inches, and during five years it was less than 6 inches, while with one exception it never exceeded 16 inches, and only once fell to 3¾ inches. These figures he states represented the minimum rainfall of the coast belt, as the record kept at Poway (elevation 550 feet) for six years shows an average 17 per cent. greater, and a record kept at Fall Brook (elevation 700 feet) indicates a rainfall 42 per cent. greater than that for the same years at San Diego. The second belt includes lands lying between 1,000 and 3,000 feet; no systematic observations have been made in this district, but the rainfall is probably from 14 to 20 inches. Mr. Hall does not state in his report what it is above 3,000 feet, but on a rainfall distribution map attached to the report it is represented as going up to 30 inches on the highest mountains.

Some of the Means of obtaining Water.

Artesian Wells.

These, when successful, form the cheapest mode of obtaining water, as the boring can be done at small cost, and as a rule, when obtained, the water is within a short distance of irrigable land.

[1] "Irrigation in Southern California," by Wm. Ham Hall. Sacramento, 1888, p. 37.

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The probable existence of artesian water is shown by the surface of the land being marshy and damp all the year round, and often by water appearing in the form of natural springs issuing from gravel beds. These springs are thrown out by belts of rock or clay intercepting the natural flow of the underground water, which, falling on the uplands, gradually percolates through the sandy bed of the canyons until the open valleys are reached. The term "cienaga" is applied to the springs and adjacent marsh.

The most important installation for obtaining water by this means that the Author visited in Southern California is near Colton in the San Bernardino Valley. Here the valley extends from east to west, and a seam of clay running from a north-westerly to a south-easterly direction crosses it between the towns of Colton and San Bernardino at a level at the surface of the ground of about 1,000 feet above the sea. The drainage-area thus partially intercepted, is from 700 to 800 square miles, the Santa Ana and other rivers flowing through it. Large quantities of water are obtained, notably for the domestic supply of the town of Riverside, and a considerable portion of that used for irrigating the Riverside district both by the Riverside Company and the Gage Canal Company. The water is reached by boring to a depth of from 100 to 250 feet. The material passed through consists of alternating beds of clay, sand, and gravel, with occasional boulders. The bore-hole is usually from 9 to 11 inches diameter lined with wrought-iron tubes. Manual labour is employed if it is not contemplated to exceed 150 or 200 feet in depth, but below this it becomes cheaper to use steam boring-tackle. The water found when passing through the gravel beds is temporarily shut out by the iron lining (the depth from the surface being noted) until the boring has been sunk to the desired depth. The tube is then slit up at the points where a flow has been noted, and the water allowed to rise to the surface. It is customary to cap the wells when water is not required. The water-bearing strata are said to be not only separated horizontally by beds of clay, but divided from each other by vertical walls of clay, and it is contended by some experts that the sources of supply to each well or group of wells are entirely independent. It is also apparently proved, to the satisfaction of some parties, that the supply is inexhaustible, and the wells will run continually without reduction of volume. At Colton, with so large a gathering-ground above, it is probable that at the present rate of abstraction the yield from the wells sunk at the lower end of the artesian area, if they are not placed too close together, will be

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maintained for a long period; but the Author was informed that the sinking of a new well sometimes reduces the yield of those near to it, and it is evident, looking at the subject simply as one of supply and demand, that in the course of time when more water is extracted than flows in from the winter rain, the normal water-level must gradually lower, drying those wells first which are situated at the highest elevation and gradually affecting the whole of them. At the date of the Author's visit (January 29th, 1890), the Riverside Company had just struck one of the heaviest flows of artesian water ever found in Southern California. This well was sunk with nine others on a tract of land just inside the artesian belt. It had been carried down to a depth of about 150 feet, and the yield was stated to be 150 miner's inches. The other nine wells which were close by were at the time all overflowing, although in smaller quantities.

The Author also visited the Pomona district at the north-west corner of the San Bernardino Valley. The artesian belt is not well defined; but is probably formed by the San Josè hills to the west, intercepting the underground water coming from the San Antonio Canyon to the north, and forcing it to the surface, forming a small river to the west of Pomona.

The wells here are much deeper, being sunk in some places to 800 feet. The yield is insignificant as compared with many of those at the east end of the valley previously mentioned; but, as they are connected to distribution-pipes at from 10 to 20 feet below the surface of the ground, it is difficult to ascertain what the flow of each may be. Wells sunk in this district have been known to fail altogether. The fact of the Pomona artesian belt giving a smaller yield than that at Colton is doubtless due to the smaller gathering-ground from which it is fed, this being probably not more than 60 square miles.

The cost of sinking these wells must be as variable as is the quantity of water obtained, on account of the depth that it may be necessary to bore, and the material met with. The Author is informed that for wells up to 200 feet in depth the cost may be from 2*s*. to 50*s*. per foot. The one just completed when the Author was at Riverside cost about £60, exclusive of plant, or 8*s*. per foot. This was sunk by hand. A gang of men to work a hand apparatus consists of a foreman at £20 per month, and three or four labourers at £10; the cost of the apparatus, exclusive of iron tubing, is £40 to £60. The cost of a steam apparatus fully equipped and capable of boring to 2,000 feet, is from £400 to £600. This can be operated by two men at 12*s*. to 16*s*. per day for wages. About two cords of

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wood per day would be consumed at from 20*s.* to 30*s.* per cord. The tubing for lining the wells cost, delivered in Southern California, 6*s.* to 8*s.* per foot.

Driving Tunnels.

In cases where a canyon of steep grade opens out into a valley, a delta of boulders and sand is formed.

By driving a tunnel into this delta from the lower end until it touches bed-rock, considerable volumes of water can sometimes be obtained. The work is one of some difficulty owing to the boulders met with, and the loose nature of the material in which the tunnel has to be driven, resulting in the frequent occurrence of caves in the roof. The bottom must be lined with concrete or boards, and the sides and roof carefully timbered, to prevent the work collapsing.

A tunnel of this description has been driven by the Ontario Enterprise at the Mouth of the San Antonio Canyon in the San Bernardino Valley. The cost is estimated to have varied from 18*s.* to £5 per lineal foot, but it is not clear whether these prices include the cost of filling up caves which occurred, or getting rid of boulders which seriously impeded the work. The total length of the tunnel is stated to be 2,850 feet, and the cost £10,000, or about £3 10*s.* per foot. In July 1888 it yielded 116 miner's inches. Similar tunnels have been driven by the Cucamonga Vineyard Company not far to the East of the San Antonio Canyon. Two of these, each 580 feet long and two others incompleted, are stated to have cost about £6,300. The complete tunnels are stated to yield 200 miner's inches.

Storage-Reservoirs.

The system of storing water in large reservoirs is gradually extending. The Sweetwater Reservoir, near San Diego, is formed by a wall of rubble in Portland cement of the following dimensions:—

Thickness at base	46 feet.
„ top	12 „
Height	90 „

The dam is curved on plan, the radius to the inner face being 222 feet; the length of chord joining the two ends is about 300 feet.

The average weight of the masonry was estimated at 164 lbs. per cubic foot. The dam impounds about 770,000,000 gallons. There

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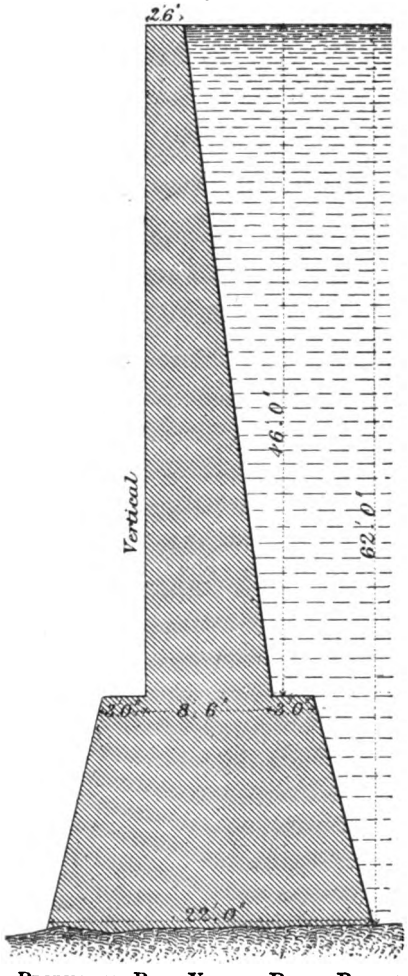
are about 20,500 cubic yards of masonry in the wall, which costs about £48,000.

Fig. 1.



PROFILE OF BEAR-VALLEY DAM. RADIUS OF CENTRE LINE, 250 FEET.

The Author is indebted to Mr. J. D. Schuyler, M. Am. Soc. C.E., M. Inst. C.E., for the above particulars, and also for the following section of the Bear Valley dam,[1] which unfortunately he had not time to visit.

This dam is also curved in plan, having a radius of about 250 feet. The transverse section is probably unique in the history of reservoir-construction, as will be seen from the profile below. The material is squared granite set in Portland cement. The dam impounds 10,000,000,000 gallons, covering 2,000 acres.

At the date of the Author's visit there were several other storage systems being talked about.

DIVERSION OF RIVERS.

In many instances the river-beds consist of great depths of sand and boulders before bed-rock is reached.

A plan frequently adopted is to construct a weir of brush-wood. This is the least expensive in the first instance, although by this means the whole volume of the stream is not likely to be diverted, and the

[1] More detailed accounts of these dams will be found in the Transactions of the American Society of Civil Engineers, vol. xix. 1888, p. 201 (abstracted, Minutes of Proceedings Inst. C.E., vol. xcvii. p. 449), and Transactions of the Technical Society of the Pacific Coast, 1889, p. 75 (abstracted, Minutes of Proceedings Inst. C.E., vol. ci. p. 337).

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weirs are periodically washed away by floods. In February 1890 the Author visited several places where the rivers had been diverted, but in no case was he fortunate enough to find any weirs of this description in good repair. In one instance all trace of the works was gone. Doubtless these weirs are repaired at small cost at the commencement of the irrigation season; but the Author cannot help expressing the opinion that works of a more permanent character would in the long run be more economical, both in the saving of annual repairs, or, more correctly speaking, renewals; and because a well-built weir would intercept a large quantity of water which now runs away through the sandy bed of the river.

Modes of Carrying Water.

The water when obtained is brought on to the land where it is to be utilized, (*a*) by means of ditches, with or without masonry lining, (*b*) by wooden flumes, (*c*) by concrete or stoneware pipes, laid out on a regular grade, and generally following the contour of the hillsides, (*d*) under pressure by iron pipes laid along the valley, in as direct lines as possible, and rising to the lands to be irrigated at convenient spots.

Open unlined ditches are the cheapest of these modes, but owing to the nature of the ground to be traversed, this adoption generally involves a great waste of water. If lined with masonry or concrete, they are more costly than timber flumes. Concrete or stoneware pipes convey the water with the least loss from evaporation, but where any leakage occurs, even if of insignificant amount, roots not larger than threads will find their way inside the pipe, and there rapidly grow until it is entirely choked up. Iron pipes have the same advantage as concrete or stoneware regarding absence of evaporation, but though made of the lightest gauge of wrought-iron customary in California, they cost more than timber flumes of the same carrying capacity, besides being reputed to deteriorate very rapidly when laid in certain kinds of soil. Under all these circumstances generally, timber flumes are found to be the most economical, and if well made of selected material, will last a long time.

Ditches lined with rubble in mortar, and faced with cement are more advantageous only in cases when the conduit is required to be of large dimensions. There are also places when the adoption of iron pipes saves a great length of flume, and more than compensates for the additional cost. Where salt marshes have to be

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crossed in the valley bottoms, as sometimes happens, the pipes are laid above the ground, resting on piers and protected with redwood boarding.

The flumes are built of California redwood, the joints being caulked and the inside sometimes tarred. The trestles which support the flume over low places or valleys are made of Oregon pine; where the ground is good, they simply rest on redwood sills, or mud-boards, but where soft, piles must be driven to obtain a foundation. These trestles, which are sometimes as much as 80 feet high, are put together in a recumbent position on the ground, and raised in place by means of ropes and tackle. After they are fixed the flume is put together on the top.

Where ditches lined with cement are adopted they are excavated entirely out of solid ground. The lining often consists of stones built in lime mortar and plastered over with cement.

The iron pipes generally used in California are made of thin wrought-iron or steel sheets, in some instances not more than $\frac{1}{10}$ inch thick, riveted together and dipped in asphaltum to prevent rust. It is claimed that by this means they become as durable as cast iron, and they have the advantage of being cheaper in the first instance and much lighter, thus effecting a considerable saving in freight and hauling. The joints of these pipes are usually made by warming the inside of the end of one pipe so as to melt the asphaltum, and driving the next pipe into it, the ends being made to fit for this purpose. It is stated that this makes a good joint, capable of withstanding an internal pressure of as much as 300 feet; where the pipes are liable to a greater pressure, it is advisable to make the joint with wrought-iron rings, and run lead into the space between the inside of the ring and the outside of the pipe.

Modes of Distribution.

It is usual when selling land with water-rights, to deliver the water to the buyer at the highest point of the lot sold, so that it will gravitate to any desired part. This involves further outlay by the seller for distribution.

Various means are adopted for this purpose. Where water is plentiful it is usually brought in unlined open ditches, incurring great waste; other means are by open ditches lined with concrete, concrete- or iron pipes, and timber flumes.

The following is approximately the cost of distribution in some of the enterprises in California:—

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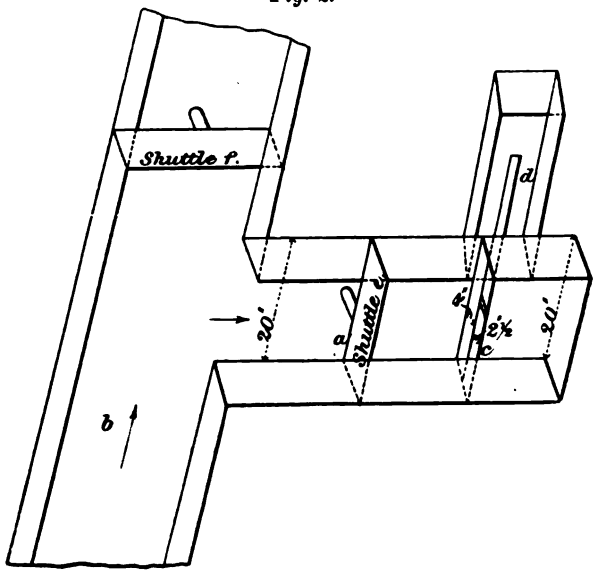
	$
Sweetwater Enterprise, wrought-iron pipes . . .	45·00 per acre
Ontario Colony (S. Bernardino), cement pipes . .	24·60 „
Pomona, cement pipes and cement ditches . . .	37·60 „
Gage Enterprise, wrought-iron pipes, cement pipes, flumes, and open ditches	15·80 „
Manugo (S. Gabriel), wrought-iron pipes . . .	18·00 „

Next to open ditches, which are objectionable on account of the waste of water involved, the most economical means is by small timber flumes. Where the land is very uneven it becomes necessary to adopt wrought-iron pipes.

Fig. 2.



When water is plentiful no particular care is taken to prevent the irrigator from obtaining more than his proper quantity, some administrations considering that the irrigator himself will restrict the use when he finds that more than his allowance is detrimental to his crop. In other cases the proper quantity is judged by the man in charge of the sluices, by the water flowing over the edge of a vertical stand-pipe, or a notch in a weir, no account apparently being taken of the velocity with which it is running.

The best arrangement that came under the Author's notice was that in use at Riverside.

This consists of a trough *a* (*Fig.* 2) branching out from the

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distributing flume *b*, having an outlet *c* at the end, 20 inches wide and 2½ inches deep, working under pressure, giving 50 miner's inches per day, or 1 cubic foot per second. This outlet can be reduced in length by pushing in a rectangular plug *d*, from the side to any extent required. The water is kept to the exact pressure required by a shuttle *e*, on the upper side of the trough, and another shuttle *f* on the distributing flume, which are regulated by moving them up and down as required.

The Paper is accompanied by the drawings from which the *Figs.* in the text have been prepared.

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(*Paper No. 2518.*)

"Fire-proof Construction."

By JOHN J. WEBSTER, M. Inst. C.E.

IN the year 1853, a Paper by Mr. James Barrett, Assoc. Inst. C.E.,[1] on the "Construction of Fire-proof Buildings," was read before the Institution. In closing the discussion, the President, Mr. James Meadows Rendel, expressed a hope that the subject would be followed by a more comprehensive Paper on the construction of fire-proof buildings generally. As nearly forty years have elapsed without the subject being again brought before the Institution, and as during that interval the question has been carefully considered by both engineers and architects, with the result that many new and improved systems have been designed, the Author has prepared a description of the various fire-proof systems adopted in this and other countries, with such other information as he has been able to gather from various authorities, and from personal experience.

There is, of course, no such thing as a fire-proof structure, if the phrase be taken in a strictly literal sense, no known substance being able to resist a change of state when submitted to the action of intense heat. In the present Paper it is intended that the word "fire-proof" shall apply to any materials or combination of materials which have been designed to resist the action of fire; whether successfully or not is immaterial. A comparison between various structures or materials can thus be instituted, and one can be described as being more, or less fire-proof than another.

There is evidence that from the earliest times attempts were made to protect buildings from fire, and also that various fire-extinguishing appliances were used; but probably the massive stone and brick walls, and columns with groined roofs, and the cemented tile and brick floors and roofs of the Romans, were designed rather for the sake of architectural effect, than from a desire to make the buildings fire-proof.

The subject may be conveniently considered under the following heads:—

(1) The fire-resisting properties of the various materials used.

[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 244.

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(2) The structural combination of materials.

(3) The general arrangement of the structures.

All these considerations are of importance, and it is the combination of the various conditions which determines the extent to which a structure is fire-proof.

Fire-Resisting Properties of the various Materials used.

The materials generally employed in fire-proof construction are—(*a*) cast-iron, wrought-iron, and steel; (*b*) stone; (*c*) brick; (*d*) concrete; (*e*) terra-cotta; (*f*) plaster; (*g*) timber; (*h*) asbestos and silicate cotton. The properties of these materials in their simple state will be first considered, and their value when forming part of a fire-proof structure, will be dealt with subsequently.

(*a*) *Cast-iron, Wrought-iron, and Steel.*—The properties of these metals at a normal temperature of, say, 60° Fahrenheit, are well known, and it is unnecessary to recapitulate them; but when they are submitted to high temperatures, the results of experiments by eminent authorities are so conflicting that it is somewhat difficult to form a definite opinion. The number of experiments on cast-iron at high temperatures is very limited, there is no uniformity in the results, which are in most cases anomalous. Sir W. Fairbairn stated in a Paper read before the British Association in 1837,[1] that it was not necessary for cast-iron to reach the fusing point to cause it to give way; and that the loss of strength in cold-blast iron in a variation of temperatures from 26° to 190° Fahrenheit was 10 per cent., and in hot-blast iron from 21° to 190° Fahrenheit 15 per cent.[2]

On another occasion, he stated that "There is not, however, any great difference in the bearing-power of cast-iron between the freezing point and when raised to 600°; but there is a sensible diminution of strength when the temperature exceeds that point, or when the bar becomes perceptibly red hot in the daylight." Again, when giving evidence before the Royal Commissioners,[3] he said that "On the whole we may infer that cast-iron of an average quality loses strength when heated beyond a mean temperature of 220° Fahrenheit." The experiments from which the fore-

[1] Report, Brit. Assoc., vol. vii. p. 409.

[2] "Experimental Research on the Strength and Properties of Cast Iron." W. Fairbairn, 1846.

[3] Report of Commission "On the Application of Iron to Railway Structures," 1849, p. 322.

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going contrary conclusions were drawn were of such a limited and unsatisfactory nature, that it is impossible to attach much scientific value to the results recorded. The investigations of wrought-iron and steel under similar conditions have been much more extensive, and, although there is a great diversity of opinion among the authorities, it is possible to form a general idea of the behaviour of these metals when submitted to high temperatures. Sir W. Fairbairn appears to have been one of the earliest to investigate this subject, and in a Paper read before the British Association at Cheltenham in 1856,[1] he stated, that with plate-iron there was no well marked effect of temperature, until a dull red heat was approached, when the tenacity rapidly decreased. With rivet-iron, the strength increased from 28 tons per square inch at 60° to 38·4 tons at 435° Fahrenheit, and at red heat the strength fell to 16 tons per square inch. Knut Styffe[2] made some carefully conducted experiments, and came to the conclusion that the strength of steel at temperatures between 212° and 392° Fahrenheit was the same as at the ordinary temperature; but that the strength of wrought-iron was greater. Mr. C. Huston[3] tested iron and steel at the ordinary temperature, at 572° Fahrenheit, and 932° Fahrenheit, and found that there was a gain of tensile strength, but a decrease of elongation with a rise of temperature. Mr. Barba found that steel at 400° Fahrenheit had an increase of strength of 30 per cent., and a decrease of elongation of 30°; that the temperature of maximum strength was 572° Fahrenheit, and that beyond that temperature the strength decreased rapidly. Mr. Barnaby made some valuable experiments for the Admiralty upon the strength of iron and steel at high temperatures; the test-pieces being much larger than those in the former experiments, the results are likely to be more accurate. He found that the maximum tensile strength of B.B. boiler iron, Bowling iron, Bessemer and Siemens-Martin steel, was at temperatures ranging between 490° and 550° Fahrenheit, and that the elongation diminished with the increase of temperature. The most elaborate set of experiments appears to be that of Dr. J. Kollmann.[4] He found a gradual decrease in the tensile strength of the iron bars from 32° Fahrenheit to the higher temperatures. A number of carefully conducted experiments was

[1] Report, Brit. Assoc., 1857, p. 405.

[2] "The Elasticity, Extensibility, and Tensile Strength of Iron and Steel." By Knut Styffe. Translated by C. P. Sandberg, 1869.

[3] Minutes of Proceedings Inst. C.E., vol. liii. p. 304.

[4] Journal of the Franklin Institute, vol. cxii. p. 241.

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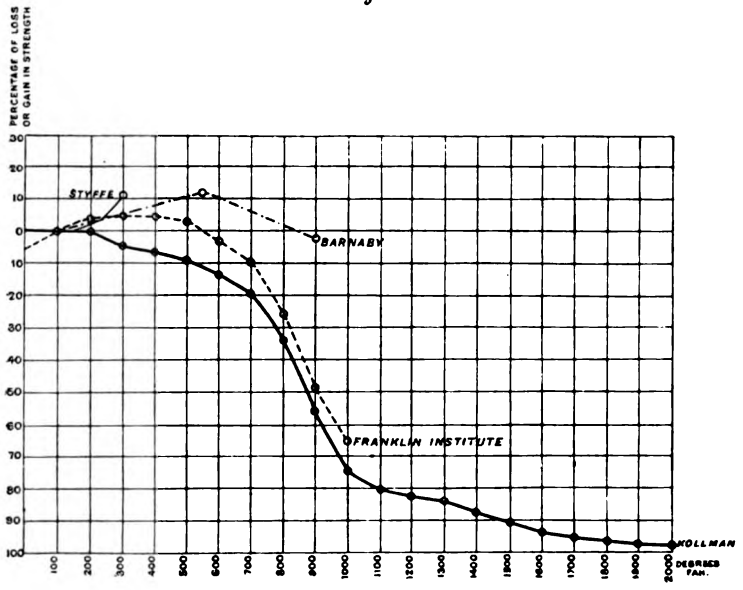
made for the Franklin Institute, which corroborated to a great extent the results obtained by Kollmann.

In *Fig. 1* the percentage of increase or decrease at various temperatures of the tensile strength of the original bar at 60° Fahrenheit, has been plotted. The vertical column shows the percentages of loss or gain of tensile strength, and the horizontal figures give the temperatures in degrees Fahrenheit.

The rate of expansion of iron increases with the temperature, but for practical purposes it may be considered that a bar 10 feet long, exposed to the fierce heat of a conflagration, which often

Fig. 1.



exceeds 2,000° Fahrenheit, would expand nearly $1\frac{5}{8}$ inch. As the force of expansion is equal to the amount necessary to compress the metal to an equal extent, it is an easy matter to calculate the enormous force which is developed either in the expansion of a bar by heat or in its contraction when cooling. The effect of quenching with water either iron or steel when red-hot depends entirely upon the form of the test-piece; and upon whether it is under the action of any external stresses. If the piece is perfectly homogeneous and symmetrical, and heated and quenched uniformly, nothing will happen beyond the alteration of the

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temper of the steel and the possible chilling of the surface of the iron; if the metal is not homogeneous and the cast-iron be at all spongy in parts, the quenching will most probably cause it to fly into pieces, principally on account of the steam generated in the crevices. But if it forms part of a structure the conditions are entirely different. If a simple riveted-plate girder without any load is heated and cooled, either suddenly or otherwise, it will not return to its original form, on account of the internal stresses set up in the various operations during construction. If the girder or column is loaded unequally, or is in any way constrained, it will neither expand uniformly with red heat, nor return to its original form or position when cooling. The extent of the distortions depends of course entirely upon the conditions referred to; beams and columns of wrought-iron and steel may be twisted out of all shape, and if of cast-iron may be fractured with cooling.

(*b*) *Stone.*—Although stone is an admirable material to use for constructional and architectural purposes, it does not resist the action of fierce heat so well as might be imagined, and very soon either cracks, shells, or calcines, according to the nature of the material. After the great fires at Chicago, at Boston, and at Paris during the Commune, it was noticed that the limestones were calcined, the fronts of buildings in many cases being entirely burnt away, leaving the brick backing standing several floors in height; the granite sometimes exploded, flying off in fragments, or slowly disintegrated to a fine sand, and where the heat was not very intense, merely cracked and scaled off. The sandstones stood the heat best, on account of the large amount of silica in their composition; but it was simply a question of time, for in many cases they were either cracked or disintegrated. The same results have been observed by the Author after many of the large fires in London, Manchester, Liverpool and elsewhere. To form an approximate idea of the comparative capabilities of the different stones to resist intense heat, the Author made a number of experiments, in which he was assisted by Mr. Thomas Morris, Works-Manager of Dallam Forge, Warrington. Cubes of the following stones were obtained:—

(1) Syenite from North Wales, used more for paving setts than for building purposes.

(2) A porphyritic granite, containing large crystals of felspar, from the quarries in Westmoreland, largely employed for building purposes.

(3) A carboniferous limestone resembling marble, from the

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Derbyshire quarries, compact and fine-grained, used for building purposes.

(4) Portland oolite.

(5) Sandstone-grit from Darley Dale, Derbyshire.

(6) Sandstone-grit from Bramley Fall, Yorkshire.

The above samples were in rough cubes, having about 5-inch sides, with the exception of the Welsh syenite, which had 4-inch sides only. They were arranged, about 5 inches apart in a row, upon a wrought-iron plate, and placed diagonally across the floor of a large heating-furnace, each stone thus receiving the same amount of heat simultaneously. The temperature of the furnace when they were first inserted was not taken by means of a pyrometer, but judging from the colour of the sides and bottom it was about 2,400° Fahrenheit. It gradually cooled down to about 2,000° Fahrenheit when they were removed nine-and-a-quarter minutes afterwards.

According to the experiments of Pouillet made with an air thermometer having a platinum bulb,[1] the following are the colours corresponding to the various temperatures :—

—	° Centigrade.	° Fahrenheit.
Dull red	700	1,292
Incipient cherry red . . .	800	1,472
Cherry red.	900	1,652
Clear cherry red	1,000	1,832
Deep orange	1,100	2,012
Clear orange	1,200	2,192
White	1,300	2,372
Bright white	1,400	2,552
Dazzling white	1,500 to 1,600	2,732 to 2,912

The door of the furnace was left partly open to enable the action of the heat on the blocks to be seen. In one-and-a-quarter minute, the Welsh syenite cracked with a slight explosion and gradually broke into shelly fragments, most of which showed the usual conchoidal fractures. The Westmoreland granite was the next to fail, a large corner breaking off in one-and-a-half minute; it afterwards cracked and crumbled to small fragments. The limestone commenced to calcine at the corners, and in about two minutes began to split up and crumble, the small pieces

[1] Comptes Rendus, 1836, iii. 782.

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becoming calcined. The Portland stone stood apparently intact for about three minutes, but a slight tap with an iron rod broke it into pieces, which commenced to calcine. The Darley Dale and the Bramley Fall stones stood the heat intact for about four minutes, when they commenced to scale and shell off. A small crack appeared in the Bramley Fall stone in about two minutes, but the other part remained firm for about four minutes. The stones were withdrawn at the end of about nine-and-a-quarter minutes, although their natural properties had been destroyed fully five minutes before. The above tests were no doubt very severe, for in the first place it would be impossible for the six sides of a stone in an ordinary structure to be exposed simultaneously to heat; and in the next place the stones were comparatively small and the intense heat was applied suddenly. The experiments, however, showed conclusively that granites are the least, and sandstones the most refractory of the stones; but that none of them possess the property to a high degree, fully endorsing the opinions formed after the great fires referred to. It was intended to quench the stones with water upon their removal from the furnace, but the heat alone had been sufficient to destroy them.

(*c*) *Brick.*—The fire-resisting properties of brick have been fully demonstrated in the many conflagrations in this and other countries. When almost every other material had perished, the brickwork remained intact. This property depends chiefly upon the amount and proportion of silica and alumina contained in the clay from which the brick is made, and also upon the amounts of oxide of iron, lime, magnesia, potash, water, &c., which are present in small and varying quantities. The greater the proportion of alumina to silica, the greater is the infusibility of the clay; and an excess of oxide of iron and of the alkalies—which act as fluxes—renders it less refractory. It is the proper combination of the various constituents which makes special bricks suitable for particular requirements. The following Table (page 256) shows the composition of a few of the well-known fire-clays and bricks, from analyses compiled from different authorities.

As the more refractory bricks are not so strong for constructional purposes, special combinations of the above materials are made to produce the blocks and bricks of the fire-proof floors described hereafter. Quenching the heated bricks with water does not appear to affect either their subsequent fire-resisting qualities or their strength, although in one or two cases when single heated bricks have been plunged into water, cracks have developed. The

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expansion of fire-brick due to the application of heat is 0·000002349 for 1° Fahrenheit; therefore a 10-foot length of floor or wall raised to a temperature of 2,000° Fahrenheit would expand 0·56 inch, or about one-third the amount of expansion of a bar of iron under similar circumstances. The average weight required to crush a Stourbridge firebrick is about 50 tons applied to the flat side of a brick 9·08 inches long by 4·4 inches broad by 2·47 inches thick, which is equivalent to 1·3 ton per square inch.

Name of Brick or Clay.	Silica.	Alumina.	Lime.	Magnesia.	Sesquioxide of Iron.	Authority.
Dowlais, South Wales	63·09	29·09	0·42	0·66	2·88	Riley.
Windsor brick. . .	84·65	8·85	1·90	0·35	4·25	Richardson.
Lee Moor	75·04	21·25	1·95	0·41	0·37	Abel.
Buckley, Flintshire .	88·1	4·5	1·2	..	6·1	Napier.
Dinas clay	98·31	0·72	0·22	..	0·18	Weston.
Stourbridge clay . .	63·30	23·30	0·73	..	1·80	Tookey.
Pioneer, Raritan, New York clay . . .	37·85	36·75	..	trace	0·95	Cook.

Name of Brick or Clay.	Potash.	Soda.	Titanic Acid.	Quartz	Water Combined.	Water Combined and Hygroscopic.	Total.	Authority.
Dowlais, South Wales	1·92	0·31	2·21	..	..	..	100·58	Riley.
Windsor brick. . .	..	..	..	..	..	..	100·0	Richardson.
Lee Moor	0·83	0·09	..	..	..	..	99·94	Abel.
Buckley, Flintshire .	0·14		..	..	..	..	99·9	Napier.
Dinas clay			..	..	0·35	..	99·92	Weston.
					And Organic Matter.			
Stourbridge clay . .	..	..	..	..	..	10·30	99·43	Tookey.
Pioneer, Raritan, New York clay . . .	0·37	..	1·6	10·5	12·3	1·00	100·32	Cook.

(*d*) *Concrete.*—Many of the fire-proof floors are now constructed of concrete of various materials, either in the form of arches or with flat ceilings, built *in sitú* or in slabs; the details of the various systems will be fully described in section 2. Although a certain material may withstand the action of fire satisfactorily, it is important to know what will be the effect upon it of water when in a heated state; for in a conflagration these two elements have to be contended with, and very often water causes the more disastrous effects. It may be mentioned that at the great fire at Lynn on Nov. 26, 1889, when buildings covering an area of

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40 acres were destroyed, the water used would have flooded the whole space to a depth of over 7 feet; and at the great fire at Boston on Nov. 28th, 1889, sufficient water was poured upon the structures to cover the site to a depth of 12 feet 7 inches.

To enable some idea to be formed of the action of fire and water upon various concretes, the Author made a series of experiments upon test briquettes of various mixtures, as follows:—

10	briquettes	of	neat	cement.				
10	„	„	1	part	cement,	1	part	sand.
10	„	„	1	„	„	3	parts	„
10	„	„	1	„	„	5	„	„
10	„	„	1	„	„	4	„	ironworks slag.
10	„	„	1	„	„	4	„	broken firebrick.
10	„	„	1	„	„	4	„	pumice-stone.
10	„	„	1	„	„	4	„	coke breeze.
10	„	„	1	„	plaster of Paris	4	„	pumice-stone.
10	„	„	1	„	„	4	„	broken firebrick.
10	„	„	1	„	„	2	„	firebrick.
10	„	„	1	„	„	2	„	ironworks slag.

The briquettes were of the form usually adopted for testing cement, and the tests were made in the Bailey cement testing-machine in the laboratory of University College, Liverpool, Professor H. S. Hele Shaw, M. Inst. C.E., having kindly placed the use of the machine at the Author's disposal.[1] As the stresses to which the various concretes are submitted in an actual structure are very similar to those met with in ordinary engineering works where cement is used, the Author felt justified in only applying such a tensile test as is usually adopted in the case of cement. Five briquettes of each set were tested at a normal temperature of about 60° Fahrenheit; the other five were carefully heated on the top of a specially built-up fire of coal and coke until they were of a light red heat, the average time of exposure to the heat being about five minutes: they were then removed, and whilst hot were quenched with water. A large number of the briquettes lost all cohesive power after being quenched, and it was with difficulty that they were removed intact; as they could not in this state withstand any tensile strain, they were allowed to dry. After three days' exposure to the atmosphere of a warm room they partly regained cohesion, and were then tested. The

[1] The briquettes were set in air, and were tested within four or five weeks after being moulded.

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details of the tests are given in the Appendix, Tables I–XII, and the following is a summary of the results:—

SUMMARY OF TESTS OF CONCRETE BRIQUETTES.

Number of Table in Appendix.	Nature and Proportions of Materials in Concrete Briquettes.	Average Weight per Cubic Foot.	Breaking Weight per Square Inch at Temperature of 60° Fahrenheit.	Breaking Weight per Square Inch after being Heated and Quenched.	Average Loss per Cent. of Original Strength after Heating and Quenching.
		Lbs.	Lbs.	Lbs.	Per cent.
I.	Neat Portland cement . . .	124·6	554·6	117·2	60·8
II.	1 part cement, 1 part sand . .	120·9	448·0	93·0	80·0
III.	1 „ „ 3 parts „ . .	111·2	100·8	18·7	81·4
IV.	1 „ „ 5 „ „ . .	109·7	74·6	15·0	79·8
V.	1 „ „ 4 „ iron furnace slag	163·08	108·1	23·06	69·3
VI.	1 part cement, 4 parts broken firebrick	95·04	84·4	30·5	50·9
VII.	1 part cement, 4 parts pumice-stone	64·8	94·58	38·3	59·5
VIII.	1 part cement, 4 parts coke breeze	71·65	69·9	39·06	57·1
IX.	1 part plaster of Paris, 4 parts broken firebrick	89·6	66·8	10·3	75·0
X.	1 part plaster of Paris, 4 parts pumice-stone	55·6	57·4	3·4	94·7
XI.	1 part plaster of Paris, 2 parts furnace slag.	148·0	223·3	6·9	96·8
XII.	1 part plaster of Paris, 2 parts broken firebrick	106·9	167·5	15·7	90·0

None of the above proportions are those adopted by the maker of any particular flooring, but they are such as to yield a good concrete under ordinary conditions, and are sufficient to enable an opinion to be formed of the strength of certain materials in combination, and of their value in fire-proof construction. The quenching test was a severe one, for it is hardly possible to have a floor heated to such an extent throughout, and so quickly quenched as these small briquettes were; but although it may be contended that the conditions were not parallel with those obtaining in a building on fire, much can be learnt by induction from the results. The face of the fracture of all the heated and quenched briquettes made with plaster of Paris was very characteristic, and is shown in *Fig. 2.* The dark ring, *a*, was well marked, the outside, *b*, and the core, *c*, being whiter and much softer than the ring *a*; no plausible explanation of this formation has presented itself to the Author. Many other con-

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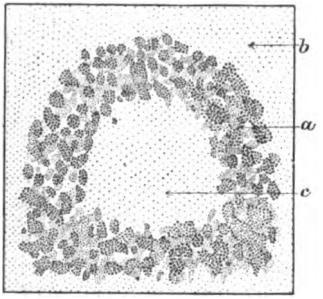
cretes are used by different makers of fire-proof floors, some containing asbestos, silicate cotton, &c., but with these the Author did not make any experiments.

(*e*) *Terra-cotta.*—This material, when great strength is not required, is often used in fire-proof construction, especially in America, for partitions, ceilings, lining of columns, furring of walls, &c. It is made from a special clay found in several localities in England. The red clays contain about 8 or 10 per cent. of oxide of iron, which renders the operation of burning difficult; the shrinkage is also unequal and uncertain, but is partially overcome by mixing different clays and adding ground pottery, glass and sand, &c. A porous terra-cotta is made by Messrs. H. Maurer and Son, of New York, which appears to be free from the foregoing disadvantages, while retaining its fire-

Fig. 2.



FULL-SIZED SECTION OF BRIQUETTE, WITH PLASTER OF PARIS AS THE MEDIUM.

resisting properties. It is composed of clay, and saw-dust, or shavings, tan-bark, charcoal, &c.; after being thoroughly mixed it is subjected to an intense heat which consumes all the combustible substances, leaving the brick porous. As this material admits of nails being readily driven into it, it is well adapted for partitions, ceilings, &c.

(*f*) *Plaster.*—The fire-resisting properties of calcined gypsum, commonly called plaster of Paris, have long been known; the builders in Nottinghamshire and Derbyshire, where the stone is found in abundance, having used this material for flooring for nearly three centuries. Gypsum is a native hydrated sulphate of lime, the finest qualities being termed alabaster, and when transparent, selenite. Plaster of Paris is made by gently calcining gypsum until nearly the whole of the moisture is

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expelled, and then grinding it. The plan adopted by the Nottinghamshire and other builders is to mix the coarse powder into a paste, and throw it on the top of the wooden joists, reeds or laths, to a depth of 9 or 10 inches, when in a few hours it sets. Gypsum is the basis of most plasters, and has good fire-resisting properties, but if not protected or strengthened by wire or other methods subsequently described, it would fail under the action of water thrown upon it during a conflagration. There are several cements and plasters mixed with other materials which certainly increase their fire-resisting qualities. Amongst them may be mentioned those made by Messrs. Hitchens, Messrs. Robinson and Co., the Cyanite Company, and by Messrs. Allen and Merritt, the latter being an American invention, and consisting of silicate of magnesium mixed with powdered flint, caustic potash, and silicate of soda, and which it is stated will withstand the action, not only of heat, but of water also.

(*g*) *Timber.*—As a material, timber alone cannot well be termed fire-resisting; but it is preferred by many to iron and brick-work for the columns and beams of mills. It is contended that large logs will not burn through, but only become charred on the outside, thus leaving the inner part uninjured. It is, however, simply a question of time and of temperature, and if the ruins after a large conflagration are inspected, in some cases large wooden beams will be found intact with only the outside charred, but in others they will be found to be burnt away entirely, and very often both these conditions are found in one ruin, showing that the fire has been fiercer in one part than another. The advantage claimed for wooden construction is that the firemen can form a good idea of how long a floor will burn without giving way, and can therefore enter the burning building with more confidence. Of the classes of timber generally used for building purposes in this country, oak is found to offer the greatest resistance to the action of fire, and the resistance of all timber is greater at the side than at the ends.

Many attempts have been made to render timber and light fabrics less combustible by coating or by injecting various solutions, the following being some of the most successful:—

Professors Bonn and Denny, of Ghent University, recommend a concentrated solution of phosphate of ammonia, but as this is an expensive material cyanide of potassium may be used. Sir William Burnett's plan is to immerse the timber for about two days, for each inch of thickness, in a solution containing 1 lb. of

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chloride of zinc to 4 gallons of water.[1] Sir Frederic Abel recommends the surface to be painted with alternate coats of silicate of soda and lime wash.[2] Maugham's patent consisted of phosphate of ammonia and starch in the proportions of 480 grains of the former to 1 ounce of starch water. Delfosse submitted the timber to the action of steam, placed it in a vacuum to withdraw all moisture, and then admitted a solution of sulphuret of calcium; sulphate of iron was then added, and to make the timber still more incombustible an acid solution of borate of soda. The use of the latter was also patented by Gratton & Rowbotham. Mr. H. Ellis used soda or potash with silicate of either magnesia, lime, or alumina and iron. A solution of tungstate of soda has also been recommended as being effective and of moderate cost. O'Connor proposed a solution of either sulphate, and carbonate, or chloride of magnesium combined with 10 per cent. of bromine. Fobacci proposed the following mixture:—American potash, 22 lbs.; alum with ammoniacal base, 44 lbs.; oxide of manganese, 22 lbs.; sulphuric acid at 60° Fahrenheit, 22 lbs.; water, 55 lbs., the sulphuric acid to be added slowly after the other substances have been dissolved in a boiler. For rendering fabrics and theatrical scenery incombustible, Messrs. Martin & Tisser, of Paris, have introduced the following:—sulphate of ammonia, 8 parts; boracic acid, 3 parts; borax, 17 parts; water, 100 parts. Sulphate of ammonia and gypsum have been used for the same purpose, and also the following composition:—boracic acid, 5 parts; sal ammoniac, 15 parts; potassic feldspar, 5 parts; gelatine, 1·5 parts; size, 5 parts; water, 100 parts. One of the later preparations is Asbestos paint, which has been adopted in many places, and to the presence of which has been attributed the prevention of the spreading of several fires. Sir Frederick Bramwell, in his Presidental address,[3] stated that it was owing to the wooden structures of the Inventions Exhibition having been coated with this paint that the whole building was not destroyed, the articles on one of the stalls having been completely consumed by fire, while the surrounding timber work was only charred beneath. In the public tests made in several large towns, when two wooden buildings exactly similar in construction were partly filled with wood and shavings soaked with petroleum and fired, that coated with asbestos paint successfully resisted the action of the fire, while the other was totally consumed. Although most of

[1] Rivington's Building Construction. [2] *Ibid.*, vol. 3.
[3] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 18.

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the above preparations are undoubtedly effective when first applied, it is a question as to how long this property lasts; and constructional arrangements will, in most cases, make a second application of the solutions very difficult, if not impossible.

(*h*) *Asbestos and Silicate Cotton.*—The fire-resisting properties of these materials are beyond dispute, and the advantage of their adoption in fire-proof construction is becoming more fully recognized. They are now to be obtained in convenient form; asbestos in either the loose fibre or in the form of cloth, millboard, wall-felt, &c.; silicate cotton, or slag-wool, in slabs of various thickness, with or without wire netting, and in the loose fibre for filling intermediate spaces in doors, floors, partitions, roofs, &c.

Structural Combination of Materials.

Having now briefly considered the fire-resisting properties of the principal building materials, a short description will be given of the way in which they have been combined by various makers to form fire-proof structures. Most attention appears to have been given to the floors; but there are other portions of the building which have to be considered with equal care, viz., the walls, columns, partitions, roof, &c. As bricks are undoubtedly the best fire-resisting materials, they should be used for all internal walls; while to obtain any desired architectural effects stone can be employed on the external faces. In fact, the nearest approach to a fire-proof structure would be a building of brick walls and columns, with brick-groined ceilings and roofs. Such a building, however, would be costly, and in most cases unremunerative, and would occupy so large an amount of space that only a small area would be available for the storage of goods. To economise space, it is necessary to use iron and steel in the construction of the columns, floors, roofs, &c. For most warehouses and public buildings it will be found to be more economical to employ cast-iron for the columns, as it is seldom necessary to have the length more than 24 or 25 diameters. Although the hollow cylinder is one of the most economical forms, it will be found that a column of cruciform section, although considerably weaker theoretically, can frequently be used to greater advantage for carrying ordinary warehouse loads; for practice often demands an excess of metal beyond the theoretical requirements of a cylindrical column, which would seldom be the case with one of a cruciform section. The latter section has also

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the advantage of adapting itself to the internal fittings of a building, and is less costly in construction. For the main and cross-girders for carrying the floors, it depends entirely upon local conditions whether built or rolled beams are more economical, but in most cases it will be found advantageous to use steel in preference to iron.

The earliest recorded attempts to make flooring fire-proof were those of the builders of Nottingham and Derbyshire, by whom gypsum was used in the manner already described. In 1766, Mr. David Hartley constructed a fire-proof house on Putney Common,[1] and in the presence of the King, the Court, and the Lord Mayor, the lower room was filled with combustible materials and set on fire, whilst the inventor and his friends were in the room above. The experiment was so successful that Parliament voted Mr. Hartley a sum of £2,500, and extended his patent to a period of thirty-one years. His method was to fix fire-plates above and below the timber flooring and fill in the space between with dry rubbish and sand. The system was, however, very little adopted. In 1778, Lord Mahon, afterwards Earl Stanhope, read a Paper before the Royal Society describing his system of fire-proof flooring.[2] This consisted of a kind of pugging; fillets were nailed to the joists about one-third of the depth of the joists, and on them were placed laths. The laths were plastered on both sides with lime and chopped hay, and then covered with a liquid grout consisting of Stockholm tar, pounded chalk, and sand, boiled together; the ceiling being formed as usual of lath and plaster. The earliest form of fire-proof floor was the brick arch springing from iron beams, and the first known example of this was in the cotton mill of Messrs. Phillips and Lee, of Manchester, erected in 1801.[3] The beams were of cast-iron, and placed about 10 feet apart. This system was very generally adopted in cotton mills and warehouses, and is even followed at the present time to a large extent, with the exception that rolled iron beams have superseded cast-iron beams. In the building regulations and by-laws of many cities and large towns in England this description of fire-proof floor is still specified, and it is only by an evasion of the by-law by an ingenious rendering of the clauses that more approved methods can be sububstited. Messrs.

[1] "A Description of the Invention and use of Fire-plates for the Security of Buildings against Fire." By David Hartley, M.P. for Hull. Reprinted 1834.

[2] Phil. Trans., 1778, p. 884.

[3] "On the Application of Cast and Wrought Iron to Building Purposes." By W. Fairbairn. 8vo. plates and cuts. Lond. 1854.

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Woodhouse and Potts modified the system by casting pockets on the sides of the beams, on which rested rolled joists, about 2 feet 6 inches apart, carrying segmental brick arches (Plate 5, Fig. 1). Another form is that of Mr. Scott (Plate 5, Fig. 2). The bays were generally 10 feet long, and on the columns were cast brackets to receive rolled joists, which were tied together by means of cast-iron beams, and upon them brick arches were turned. Although there is a saving of brickwork in this system, a large amount of the ironwork appears to be exposed, which would be a serious defect in a fire. Sir William Fairbairn introduced the form of floor (Plate 5, Figs. 3 and 4) in which the intrados of the arch consisted of plate-iron $\frac{1}{4}$ inch thick, in widths of 3 feet, riveted together by means of T-irons 4 inches by 2 inches by $\frac{5}{16}$ inch. Tie-bars, at distances of 9 feet, were fixed to the top of the rolled iron beams, which were 10 feet apart, the space between the plates and the floor-line being filled with concrete. The floors were then laid as desired, in either flags, tile, wood or cement. A modification of this system was introduced by Mr. Moreland, in which corrugated iron was used in place of the flat plates (Plate 5, Figs. 5 and 6). The objection in both cases is the exposure of so much iron. Owing to the great weight of the ordinary brick-arch floors, Sir William Fairbairn introduced in the design of the Saltaire Mills, built in 1854, hollow brick-arch floors (Plate 5, Figs. 7 and 8). The beams are of cast-iron, spaced 10 feet apart; the arches have a rise of 12 inches to the crown, and the hollow bricks shown in detail (Plate 5, Fig. 8), are 9 inches deep at the springing and $4\frac{1}{2}$ inches at the crown; the space above to the floor-level is filled with lime and ashes, and paved with flags or tiles.

The advantage of hollow bricks has been known for a long time to both English and French builders; but the first patent taken out for their manufacture appears to be that of Benford Denton in 1812. The bricks up to this time were all made by hand, but in 1842 Mr. Collar, a Frenchman, obtained a patent for making them by machinery. The machinery, however, was not successful, and Mr. Robert Beart, of Godmanchester, took out a patent in April 24, 1845, which has since worked satisfactorily. These two patents led to a long and interesting law-suit between the French and English inventors, the former asserting that the latter had infringed his patent.

Arch Pots.—Hollow bricks known as "Arch Pots" were extensively used at one time, the floors of Buckingham Palace and some of those of the National Gallery, the Treasury buildings,

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the United Service Club, the dome of the Bank of England, &c., having been constructed with them (Plate 5, Fig. 9). An enlarged view of the pots is shown in Fig. 10. The span of the arches was generally about 6 feet and never more than 7 feet, the rise never exceeding 6 inches. The pots were about 8 inches high, 4¾ inches square at the top, and the same diameter at the bottom; the sides and bottom were scored, and a small hole was made in each to act as a key for the mortar.

The first departure from the brick-arch floor appears to be that designed by Dr. Fox, of Bristol, and improved by Mr. Barrett, known now as the "Fox and Barrett" system. This consists (Figs. 5, 11, and 12) of small rolled joists, placed about 20 inches apart, and resting upon the main girders, strips of wood about 1¼ inch square being laid upon the bottom flanges about 1½ inch apart. Upon these strips and between the joists the concrete was laid, the ceiling being plastered as usual, and the floor laid as desired with wood, flags, or tiles. A full description is given in a Paper communicated to the Institution by Mr. Barrett in 1853.[1] This was the first system in which any attempt was made to protect the iron joists. It was adopted in the Liverpool Exchange buildings, the cellars of which extended under the whole of the large space known as "The Flags," and are used as bonded vaults. In the construction of the roof which forms the floor of the "Flags," a modification of the Fox and Barrett system was suggested by one of the foremen. Instead of the strips of wood, he placed hollow tiles of triangular section (Figs. 13 and 14) which decreased the weight, increased the strength, and offered greater resistance to fire, both on account of the nature of the material and of the enclosed air space; in addition to this the concrete above could be laid without the use of the flat centres below. Mr. Barrett gives the following comparative weights:—wooden floor, 35 to 40 lbs. per square foot; Barrett's, 78 lbs. per square foot; 4½-inch brick-arch, 70 lbs. per square foot; 9-inch brick-arch, 120 lbs. per square foot.

The floor designed by Mr. Clark Bunnett is a flat floor of concrete somewhat similar to the Fox and Barrett system, the wood fillets being fixed to the top flange with clips, and the concrete filled in on the top of a flat centering to the level of the fillets. A layer of mastic is spread over the concrete, and the flooring boards or blocks secured to the fillets. In 1862 Mr. Allen took out a patent for a special concrete composed of Portland or other

[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 244.

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cement mixed with cinders, slag-coke, or clinkers, in the proportions of 1 of cement to 6 of the other materials for strong, and of 1 to 8 for ordinary, concrete. This he used in place of stone for arches of flooring and for other portions of buildings. At the large fire in the six-storeyed premises of Messrs. Waterlow, of Finsbury, in 1871, when all the iron and stonework were destroyed, lintels made of Allen's concrete were not affected by the intense heat. Mr. Bunnett designed a special flooring, consisting of hollow bricks joggled at the sides, somewhat similar to those used by Sir William Fairbairn in the Saltaire Mills. Wrought-iron tie-rods were encased in the brickwork and locked the bricks together, each being supported by those adjoining. The floors of the Grosvenor Hotel, and of the Victoria Station, Pimlico, are built on this system. An experimental arch of 15 feet span, with a rise of 2 feet 3 inches, withstood satisfactorily a load of 267 lbs. per foot superficial, the deflection being about $\frac{2}{16}$ inch.

One of the earliest to fully realise the importance of protecting the ironwork of the girders was Mr. Whichcord, who, in 1873, devised a special fire-brick casing which enclosed the web and lower flange of the iron girder, as shown in Fig. 15. The blocks were about 9 inches long, and so designed as to form a skewback to receive the arch bricks; the bricks and blocks were set in cement, allowance being made for expansion. He constructed an experimental furnace, 15 feet long by 10 feet by 5 feet, in which he placed the joist encased in fire-bricks, from which sprung side arches to the walls of the furnace, to represent as nearly as possible a floor. It was loaded with 6½ tons distributed, being one-fourth of the actual breakingweight. A fierce fire was then kept up for two and a half hours, when the bricks were suddenly quenched with water. The beam having deflected 1¼ inch when hot regained its normal position when cool, and, beyond the bricks being vitrified, no damage was done. A second experiment was made, after rebuilding the furnace, by submitting it to a fierce fire for one hour and a half, and a slow fire for twenty-seven hours, and then quenching by means of a jet from a hose. The results were very satisfactory, the firebricks being uninjured, and the iron joists perfectly straight and sound. Mr. Archibald Dawnay, Assoc. M. Inst. C.E., introduced a system consisting of a solid block of concrete between the joists, with a flat ceiling. Either ½-inch square iron bars, 12 inches apart, or 3-inch iron joists, 1 foot 6 inches apart, rest on the lower flanges of the binding joists, which, for a 7-foot bay, would be 5 inches deep; flat centering is then placed below the joists, and concrete, consisting of Portland cement and broken fire-clay, is

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filled in, effectually protecting them on the under side. The flooring and ceiling can be made as desired, the different arrangements being shown in Figs. 16, 17, and 18. The weight for a 12-foot bearing is 40 lbs. per square foot, and it is capable of bearing a safe load of 2 cwt. per square foot. A modification of Fox and Barrett's system, designed by Mr. Phillips, was introduced by Messrs. Measures Brothers in 1862. It consisted of a concrete floor having T-iron bars spaced about 9 inches apart in place of the wooden ones (Figs. 19 and 20). In more recent designs (Figs. 21 and 22) light rolled-iron joists are embedded in the concrete. The flooring-boards are laid upon light wooden joists secured to the upper surface of the concrete, leaving an air space between, which, it is claimed, prevents dry rot and deadens the sound. The disadvantage of this system appears to be that there is so much ironwork unprotected. Messrs. Homan and Rodgers have obtained several patents for fire-proof floors, the first being in 1865 for a concrete arch of a normal span of 10 feet. The objection to this system was the weight—about 1 cwt. per square foot—and the cost of the centering. The next patent, taken out in 1871, was for the flat type (Figs. 23 and 24) having steel or iron joists embedded in the concrete. The weight per square foot of such a floor, 20 feet by 10 feet, capable of sustaining a load of 2 cwt. per square foot safely would be 56 lbs. The third patent, taken out in 1885 (Figs. 25 and 26), claimed the use of special hollow bricks, carried on rolled joists which supported the coke-breeze or other concrete, the latter being laid without the use of centres. This system is similar to the one adopted under the "Flags" at Liverpool (Figs. 13 and 14). Any of these floors can be finished on the surface with granolithic, asphaltic, tiles, wood blocks, or any other material used for this purpose; and, as the bricks are moulded with longitudinal grooves underneath, they make a good key for plaster. They have been used by the London School Board, in the General Post Office, the People's Palace, Queen Anne's Mansions, and other large buildings. Messrs. W. H. Lindsay & Co., of Paddington, adopt an effective combination of iron and concrete, the floor and ceiling being flat. The size and distance apart of the rolled joists of iron or steel depend upon the load and span. They are strengthened by means of trussed-rods passing under and over the joists alternately, at intervals of about 18 inches. The whole of the ironwork is then embedded in "pumice concrete," consisting of coke-breeze, sand and Portland cement, and weighing about 80 lbs. per cubic foot. The advantage of this plan is that the truss-rods, besides giving

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additional strength, sustain the concrete in position. Another form of flooring is adopted by these makers in which the truss-rods are dispensed with, and the pumice concrete is fixed in the form of slabs, and not *in situ*. Both systems, with the different methods of fixing the flooring-boards, are shown in Figs. 27 and 28, Plate 5.

Provisional protection was granted to Mr. Richard Moreland, Jun., in 1866, for the invention of a form of floor shown in Fig. 29. It consisted of iron-framed girders resting on each side of the column, and continuous to the end of the building. Cross-girders in the form of bowstring girders, and made of angle-iron with flat-iron connections, were fixed one over each column and others spaced about 3 feet 9 inches apart. The whole was then encased in a solid block of concrete, forming a floor of great strength; with the main girders 12 feet apart and 10 feet 9 inches long and 15 inches deep, the floor would carry safely a load of 3 cwt. per square foot. The advantage of this system was that the concrete was continuous, and not broken into sections by webs of cross girders.

It is reported that a strike amongst the carpenters of Paris in 1840 induced the master-builders to substitute iron and concrete for timber flooring, the systems of Vaux and Thuasne being those generally adopted. The former consists of flat plates or bars bent at the end, as shown in Fig. 31, and resting on the walls; upon these bars are bent square iron rods, which carry cross rods. Flat centres are placed underneath, and the concrete thrown down, embedding the ironwork completely. In the Thuasne system, rolled iron joists are used, slightly arched and placed 2 feet apart centre to centre. They are connected at about every 3 feet by flat-iron ties, the ends being turned over the top flange of the girder, and upon them are placed the square rods as in the Vaux system, the concrete being also laid in a similar manner. The ceilings in both cases are finished in plaster, and the floors can be laid with any material desired. This system was adopted at the Louvre in Paris. Another floor very generally used in Paris, consists of an arch of hollow bricks springing from rolled joists, the soffit of which is finished in plaster of Paris to form a flat ceiling. The size and distance apart of the joists depend upon the loads to be borne and upon other conditions. An ordinary wooden floor is laid on the joists.

A system introduced many years ago by Messrs. Dennett and Ingle, of Nottingham, has been adopted in many important buildings, including the new Foreign Office, Home and Colonial

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Offices, the Town Hall, Manchester, and Her Majesty's Theatre. It consists of an arch of concrete, having sulphate of lime or gypsum for its base, the other constituents being broken bricks, stone débris, furnace dross, &c. The concrete is spread upon specially constructed centres, and the spandrels are either left open or filled up to the floor-level, as shown in Fig. 32. A section through the ceiling over the Cabinet Council Room of the New Foreign Office is shown in Fig. 33, the dome being 36 feet diameter, and with a thickness of 9 inches at the haunches. A section through the domed vault, over the ladies' dressing-room, at Her Majesty's Theatre, is shown in Fig. 34. This dome is 30 feet × 20 feet × 5 feet. Many experiments have been made with these floors with very good results, the 8-foot span of Her Majesty's Theatre bearing safely a load of $3\frac{3}{4}$ tons per square foot. Experiments by impact are, however, useless when the load is applied to one spot; for it is possible to send a shot through a pane of glass without shattering it, and yet the same ball would probably not stand on a similar piece of glass without breaking it. A floor, patented by Mr. Joseph Bunnett in 1858, was formed of hollow bricks having the two sides each composed of two parallel inclines half the depth of the block; tie-rods bound the bricks to the angle-iron wall-plates, and formed a slight arch. The construction is shown in Figs. 35, 36, 37, 38, and 39, Plate 6. Arches of this design have been made with a span of 21 feet, and a rise of only $2\frac{3}{4}$ inches. An experimental arch of 15 feet span and 2 feet 3 inches wide, carried a distributed load of 267 lbs. per square foot with a deflection of $\frac{9}{16}$ inch; each brick was $10\frac{3}{4}$ inches long × $9\frac{3}{4}$ inches wide × 6 inches thick, and weighed 21 lbs.; they were joined together with Portland cement and sand. Mr. Thaddeus Hyatt has obtained several patents for fire-proof floors in which iron is used in combination with concrete. One system substitutes flat bars 2 inches × $\frac{1}{4}$ inch for the small rolled-joists. In another system angle-irons are riveted to the underside of the girders to carry the $\frac{1}{4}$-inch wires crossways, which act as a key for the concrete; ceiling holders, $2\frac{1}{2}$ inches deep, and notched at the ends to slip on the flanges of the joists, are placed 2 or 3 inches apart, and the concrete is then laid, light timbers being used to which the flooring can be attached. Another system (Figs. 40 and 41) is the subject of a later patent. In addition to the vertical bars embedded in it, the concrete is arched from one bar to the other, and kept in position by tie-rods encased in a mixture of either plaster of Paris, concrete, or other fire-proof material. Blocks of glass of various forms are placed in it at intervals

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to illuminate the space below and so dispense with windows, which Mr. Hyatt contends are a source of danger in a fire. This system is claimed to be a "self-supporting illuminating beam-arch." A patent was obtained by Mr. Hornblower, of Liverpool, in 1871 and 1873, for the fire-proof floor shown in Fig. 42. Wrought-iron rolled-joists of a section suitable for the span and load are fixed 2 feet apart, and encased in hollow skew-backs of fire-clay; these are filled with concrete, and a hollow brick of fire-clay fills in the space between the skewbacks, forming a flat ceiling. The whole is then grouted with cement, and any flooring can be laid. Grooves are moulded on the materials of the blocks to act as a key for the plaster of the ceiling. This system was adopted in the Manchester Pantechnicon, and in the Liver-pool Corn Exchange. The floor shown in Figs. 43, 44, 45, and 46, was patented by Mr. George Northcroft in 1876, and is somewhat similar to Hornblower's, the skewbacks and voussoirs being of a different form, specially designed to allow for ex-pansion. The bricks are of various shapes, and are mutually supported by a series of projections fitting into each other. The joints of the bricks and skewbacks are radiated, the beds of the tongues and grooves being level, and the back-joints at right angles thereto; the bricks are set in mortar, cement, or fire-clay, but the girders are surrounded with an asphalt bedding, so that in case of over-heating the asphalt would soften and allow free expansion and contraction. The ends of the joists and side skewbacks rest on a cast-iron bond-plate forming a continuous tie round the building; shoes are cast to receive the end of the girders, which rest on balls or rollers to facilitate expansion. The ceiling is fixed by means of the grooves cast on the underside of the blocks. The intermediate space between the skewbacks and the centre wedge brick may be either filled with concrete or left for ventilation.

Messrs. Doulton and Co., of Lambeth, have introduced a form of flooring (Fig. 47) in which hollow skewbacks encase the joists or girders, the voussoirs consisting of hollow bricks having the sides parallel with the angle of the skewbacks. The bricks are made of a special fire-clay which experiments have proved to be unaffected by high temperatures, or by the application of water when heated. In addition to the shoulder on each face, they have a dovetail-groove for the jointing cement to run in and form a key, the underside being also grooved to serve as a key for the plaster of the ceiling, should one be desired. This system has been applied at Whiteley's, the London Pavilion, large pre-

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mises in Corporation Street, Birmingham, and the National Provincial Bank. A floor, having a span of 8 feet is laid at the works of Messrs. Doulton, and has been submitted to the following severe experimental tests:—it was loaded to the extent of about 5 cwt. per square foot, and after a severe fire had been burning underneath for several hours a hose was turned on to it with the result that the floor remained uninjured.

The floor (Fig. 48) made by Mr. M. H. Blanchard, of Bishop's Waltham, consists of a series of blocks of terra-cotta, fitted between iron or steel joists spaced about 2 feet 6 inches apart. The sides of the bricks are joggled, to fit into one another, and they are drawn and held together by means of tie-rods passing through them and the joists. They are perforated longitudinally by a number of holes, to decrease the weight of the floor. No plaster is used for the ceiling.

Mr. W. Lindsay, jun., has devised a floor, the construction of which is shown in Fig. 49, Plate 6. It consists of hollow rectangular bricks with an internal rib, and joggled at the sides to enable each brick to support the one adjoining it; the underside is grooved to form a key for the plaster of the ceiling. The bricks are 2 feet long, 4 inches wide, and 4½ inches deep, and can be laid either to form an arch up to 9 feet span, or as a flat soffit. In the flat construction the rolled-joists are placed about 2 feet apart, the bricks resting upon either the top or bottom flange, concrete being laid upon the top. The bottom of the rolled joist is protected by a flat tile running longitudinally and supported by the ends of the bricks; and the top is covered by an inverted channel-section tile of the same material as the bricks. The crushing strength of the bricks is stated by the maker to be 365 tons per superficial foot; in the flat construction they would, of course, be submitted to a transverse strain. The form called "trough-flooring" (Fig. 51) is constructed by both Messrs. W. H. Lindsay and Messrs. W. Lindsay and Co. The troughs are fitted with pumice-concrete, in which, to reduce the weight and to provide ducts for ventilation, earthenware pipes are embedded. The ceiling can be formed either by securing wooden strips to the bottom of the trough to receive the lath and plaster, or by attaching to the lower flange inverted T bars to receive earthenware tiles, or again by suspending concrete slabs by bolts from the top of the trough. This form of flooring is of great strength, and large spans can be covered without the use of main girders. Mr. Mark Fawcett has recently introduced the system shown in Figs. 52 and 53, which consists of tubular tiles laid diagonally on the lower

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flange of the iron or steel joists, placed 2 feet apart from centre to centre, being the diagonal of the tile at right angles to the joist. The bottom of the tile is flat, and flanged so as to touch the adjoining one, leaving a space above to receive the concrete. The ends of the tiles are joggled and rest on the joist, serving to protect the underside, but a space is left under the joist to form a free passage for the air. The concrete on the top bears directly on the joists, thus relieving the strain on the tiles, the underside of which is scored to form a key for the plaster of the ceiling. Floors on this system have been laid at the Children's Hospital, Great Ormond Street, and the Albert Hall Mansions. The Pioneer Fire-proof Construction Co., of Chicago, has introduced the "hollow tile flat arch system" (Figs. 54–60). The section of the bricks depends upon the depths of the floor, which is in turn governed by the span. In each case the bottom of the joint is protected by a longitudinal tile of the same material as the brick. In Fig. 60 the bricks are shown to form an arch of 20 feet span, the spandrels being filled in with concrete hollowed out for lightness. The thrust of the arch requires tie-rods at intervals, and as these come below the soffit, they would, unless protected, be a source of danger during a fire. Iron tie-rods, $\frac{3}{4}$ inch diameter, are also fixed in the flat arch system, bolted to the web of the girders at spans of from 8 feet to 10 feet. The following Table shows the weights of the various floors and the size of the joists as given by the manufacturers:—

HOLLOW TILE FLOOR ARCHES.

Depth of Tile.	Description.	Maximum Safe Span.	Weight per Square Foot.	Sizes of Iron Joist.				Safe Load per Square Foot.
				14 Feet Span.	18 Feet Span.	22 Feet Span.	26 Feet Span.	
Inches.		Feet Ins.	Lbs.	Inches.	Inches.	Inches.	Inches.	Lbs.
6	Fig. 54	4 10	23	6	7	8	10	250
6	„ 54	5 6	29	7	8	9	10	„
6	„ 54	7 6	40	9	10	10½	12	„
7	„ 54	5 0	25	7	8	9	10	„
8	„ 54	5 6	29	7	8	9	10½	„
9	„ 54	6 0	33	8	9	10	12	„
10	„ 55	6 0	37	8	9	10	12	„
10	„ 56	6 6	40	9	10	10½	12	„
12	„ 57	7 0	48	9	10	10½	12	„
5	„ 60	15 0	28					
6	„ 60	20 0	35					

Messrs. Henry Maurer & Son, of New York, construct fire-proof floors on the system shown in Figs. 61–65, the bricks used being

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hard-burned fire-clay, hollow, of equal vertical thicknesses, and laid in cement mortar to break joint alternatively. They have dovetail-grooves in the side and bottom to form a key for the cement and for the plaster of the ceiling. The following Table furnished by the manufacturers, shows the weight of the various floors, exclusive of the joists, the girders and joists being in all cases protected with the material :—

HOLLOW BRICKS FOR FLAT ARCHES.

Depth of Brick.	Maximum Span.	Weight per Square Foot.	Safe Load per Square Foot.
Inches.	Feet. Inches.	Lbs.	Lbs.
6	4 0	29	1,000
7	4 6	33	1,200
8	5 0	37	1,400
9	6 0	40	1,500
10	6 6	43	1,500
12	7 0	48	1,800

The Raritan Hollow & Porous Brick Company, of New York, construct fire-proof floors either in flat or segmental arches (Fig. 66). The bricks are of hard-burnt clay, and the ironwork is protected by the skewbacks being returned under the joists. Longitudinal grooves are moulded in the faces of the bricks, to form a key for the cement and plaster of the ceiling. The following Table gives the weights and safe loads :—

Depth of Brick.	Maximum Span.	Weight per Square Foot.	Safe Load per Square Foot.
Inches.	Feet. Inches.	Lbs.	Lbs.
6	4 0	29	1,000
7	4 6	32	,,
8	5 6	35	,,
9	5 9	37	,,
0	6 6	41	,,
2	7 6	48	,,

On comparing the Tables of the last three manufacturers it is difficult to reconcile the great difference existing between the safe loads of floors of practically the same construction; the strength of one system being given as about four times that of another.

Having now described a number of the combinations of iron, concrete and brick, other methods of fire-proof construction may

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be briefly considered. Returning to the system of pugging, which is extensively adopted both in this country, in America and in France, the application of silicate cotton may be mentioned. Figs. 67 and 68 show the way in which it is used by Messrs. D. Anderson & Son. In the first arrangement, silicate slabs are secured underneath the wooden joists by means of wooden strips to which is fixed the usual lath and plaster ceiling. In the second arrangement, fillets are nailed to the sides of the joists to receive boards which carry the silicate cotton either in the loose state or in slabs. In the first arrangement the joists are protected from fire underneath, and in the second on the top; by combining the two the protection is more perfect. Mr. Wilkinson, in addition to the arch made of his special concrete, has a system of pugging (Fig. 69) in which fibrous plaster is used. Fillets of wood fixed on the side of the wooden joists at about two-thirds of the depth down, carry the slabs of fibrous plaster, a fillet of plaster being laid on the top.

In connection with the plastering of ceilings, walls, partitions, &c., it is advisable that some efficient key should be adopted for retaining the plaster in the event of its becoming wet. A patent was taken out by Mr. L. Leconte, in 1841, for using wire-netting instead of laths, but this had been previously done in the building of the Pantechnicon. A combination of wire-netting and hoop-iron is used to a great extent in America, and a system has been patented by Mr. Richard Johnson, of Manchester, consisting of galvanized wire-netting with $\frac{3}{4}$ inch or smaller meshes laid on strips of varnished hoop-iron about $\frac{5}{8}$ inch wide, fastened by special staples edgeways across the joists from 6 to 9 inches apart. This invention had a practical test in the large fire on the 5th of November, 1889, at Messrs. Crabtree's Dye Works, Manchester, the superintendent of the Manchester Fire Brigade reporting that it stood the test of a fierce fire and of water satisfactorily, the damage being very slight.

Another ingenious form of wire-netting is that invented by Mr. Golding, of Chicago, and manufactured in this country by the British Expanded Metal Company at West Hartlepool. It is made by cutting parallel slits in a thin bar or plate of iron, and then expanding it; a network is thus formed, the form of the meshes being governed by the distance apart of the slits. The Author adopted this material in the plaster covering of the full-sized model of the Eddystone Lighthouse, designed by him for the Committee of the Royal Naval Exhibition, 1891, and erected in the grounds under his superintendence.

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Solid Wood Construction.—There are many advocates of the solid wood system, and in America what is called the "mill construction," or "slow-burning construction," is extensively adopted. The principal features of this system are outside walls of masonry, or preferably of brick, concentrated in piers and buttresses, with thin walls containing the windows between; the floor and roofs are constructed of large timbers, covered with thick planking, the girders being supported by wooden columns; no furring or concealed spaces or anything which will conceal fire or allow dirt to accumulate being permitted. The floor beams are generally 14-inch × 12-inch hard pine timber resting upon 20-inch brick piers in the basement, and on wooden posts and the outer walls in the other storeys. The beams have an air space round the end as shown in Fig. 71, Plate 6, and are anchored to the wall by a cast-iron plate on which they rest; this plate having a projection which fits into a groove in the bottom of the beams. The upper edge of the beam is slightly rounded, so that in the event of its getting burnt it would fall without pulling down the wall. The floor consists first of 3-inch planks, not exceeding 9-inches in width, planed on both sides, grooved and tongued with hard wood. The nails are driven obliquely through the grooves in the planks before the tongues are put in. Upon the planking is spread $\frac{3}{4}$ inch of mortar to preserve the timber from decay, to prevent the floor from becoming soaked with oil, and to increase the slow-burning property of the construction. Above this is laid the upper floor of $1\frac{1}{4}$-inch boards. The columns are usually round, 9 inches least diameter in the first storey, 8 inches in the second, and 7 inches in the third, and are made of thoroughly seasoned hard pine or oak. A hole $1\frac{1}{2}$ inch in diameter is bored down the centre of each column, from end to end, with two transverse holes, each $\frac{1}{2}$-inch diameter, at the top for ventilation and the prevention of dry-rot as shown in Fig. 71. No timber is varnished or "filled" until three years after its erection, for fear of dry rot. The cost of such a mill in the United States would be as follows:—

Mill with three storeys for machinery and basement for miscellaneous purposes .	75 to 80 cents per square foot of total floor arch.
Mill with two storeys and no basement .	65 cents per square foot of total floor arch.
Mill with one storey of about one acre of floor, with basement for heating and drainage only	85 cents per square foot of total floor arch.

The solid wood system of Messrs. Evans & Swain is shown in Figs. 72 and 73, Plate 6. The flooring consists of solid wood

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joists, constructed of timbers varying in depth from 4½ inches in 8-foot spans to 11 inches in 30-foot spans; they are closely laid and spiked together alternately and rest on the wall direct, no plates being required. Before being fixed each joist has the two bottom edges cut with an angular groove, so that when two come together a dove-tail groove is made, forming a key for the plaster of the ceiling. The beams and columns are constructed in a similar manner, and when used for large spans are built up of smaller timbers. This system has been adopted with satisfactory results in large warehouses for the East and West India Docks, the London, Tilbury and Southend Railway Company and Westminster Hall.

Columns.—As the metal of the columns would be affected either by intense heat, when it would collapse, or by water, when it might possibly crack, it is absolutely necessary that all columns should be protected. Figs. 74, 75, Plate 7, show the plan adopted by the Raritan Hollow and Porous Brick Company for protecting round and Phœnix columns. Circular blocks of porous terra-cotta, about 12 inches high, are made to fit the diameter of the column; they are perforated with holes about ⅜ inch diameter and 2 inches deep, so placed as to correspond with those in the adjoining block. Small iron pins are dropped in the holes, and the whole embedded in mortar. For square columns, porous terra-cotta slabs are used. In each case the blocks or slabs are scored outside to form a key for the plaster coating. Figs. 78 and 79, Plate 7, show the form of hollow tile adopted by Messrs. H. Maurer & Son; the blocks are set in gauged mortar and tied circumferentially by copper wire before plastering. Figs. 80–83, Plate 7, illustrate the method of the Pioneer Company, in which hollow tiles are secured in segments by means of iron clips, the courses breaking joint, and the whole being finished in cement. Figs. 84 and 85, Plate 7, show the system of Messrs. Dennett & Ingle, corrugated strips of iron being secured to the columns by means of wire, forming a key for the concrete which is afterwards moulded round it and finished with cement or plaster. The wire-lathing of Messrs. Johnson, Clapham & Morris, already described, and the expanded-iron lathing, are also employed for protecting columns.

Partitions.—The hollow brick of fire-clay or porous terra-cotta is used with advantage in forming partitions and for the furring of walls. Figs. 86–90 show the plans adopted by various English and American manufacturers.

Roofs and Ceilings.—Flat roofs and ceilings are made by suspending fire-clay or terra-cotta tiles to the iron of the roofs in a

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manner somewhat similar to that adopted in the various floor sections, the tiles or bricks being, of course, much lighter.

Doors and Window Shutters.—The doors of fire-proof structures in England are generally made of either single or double-plated iron, the latter having an air space of about 2 inches between the two thicknesses of plate. They either run on a rail let into the floor or are suspended from an upper rail. For outer doors, a small hand-hole is made in the plate for the firemen to have access to the opening-gear; this hole is covered by a plate inside, held in place by two bolts or pins, the joint being made with thin cement, so that a slight blow will release it. Several automatic arrangements are employed in the case of inner doors to close them when a certain temperature is attained. These appliances are very ingenious, but often fail at the critical moment. It is, therefore, a better plan to make the door always close automatically unless it is held back. The holding-back arrangement can easily be controlled from different parts of the structure. The window shutters are generally of iron, single-plated, and made to swing. In the American slow-combustion construction the doors are made of wood covered with tin, the ceilings and columns often being protected with this material also. The window guards are made in a similar manner.

Fire-proof Theatre-Curtains.—From the statistics contained in Mr. Walter Emden's Paper on "Theatres and Fire-proof Construction," read before the Society of Arts in January, 1888,[1] it appears that between the years 1850 and 1860 sixty-nine fires in theatres occurred; between 1861 and 1870 there were ninety-nine; and between 1871 and 1880 one hundred and eighty-one; and also that during the eleven years ending 1887 no less than two thousand and fifty-six persons lost their lives in fires in theatres, making an average of about one hundred and eighty-seven deaths per annum. This calls for legislation to protect the public, but the great difficulty would be to legislate for existing structures which, to be made fire-proof, must be practically rebuilt. In new structures, however, advantage is taken of the many excellent systems of fire-proof constructions, and old buildings can be protected to a certain extent at a comparatively small cost. In Liverpool, Manchester, and other large towns, the magistrates will not grant a licence to a theatre unless it has a fire-proof curtain separating the auditorium from the stage, although the local by-laws do not require one; and an undertaking has to be

[1] Journal of the Society of Arts, 1887-88, p. 221.

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given that the curtain will be lowered and raised at least once during each performance. Although the London County Council does not enforce such a condition, many managers of London theatres have adopted fire-proof curtains; others consider them unnecessary so long as their theatre is built of stone and iron and illuminated by the electric light.

The curtain is generally constructed of sheet-iron or steel, double-plated on a light iron frame with an air space between; the plates are sometimes corrugated for strength and lightness, and the space between may be filled with either asbestos or silicate cotton. The curtain may also be made of asbestos cloth, fixed to a light framing, or of a combination of wire-netting and silicate cotton or plaster. In any case it slides in iron guides secured to the proscenium walls. If worked by hand, an ordinary winch arrangement is attached to the cross-head of the curtain, which is counterbalanced by weights slightly less than its own, so that it can be lowered quickly by gravity, but under control of the brake. Many curtains are worked by hydraulic power obtained from either the ordinary low-pressure mains, the Hydraulic Power Company's high-pressure mains, or a private local supply. The power is applied by employing a direct-acting ram at each end of the cross-head carrying the curtain, the arrangement shown in Figs. 91 and 92, Plate 7, being that erected by Messrs. Clark, Bunnett & Co. at the Court Theatre, Liverpool, and is typical of the system. An ingenious arrangement for working these curtains has been devised by Mr. T. W. Stead, of Halifax, and is shown in Figs. 93 and 94, Plate 7. The curtain itself, which may be constructed of any of the materials mentioned, is made in halves, coupled by steel ropes and pulleys, so as to open or close together from or to the centre, one acting as a counter-balance to the other. The top half A is heavier than the bottom half B, so that the normal condition of the curtain is to be closed; in the bottom half, however, is fixed a tank C to contain water, fitted with the necessary feed and discharge pipes having swivel joints. If it is desired to raise the curtain—or rather to raise the top half and lower the bottom one—the tap is turned, the tank fills and makes the bottom half the heavier, causing it to descend and raise the upper one. To lower the curtain the discharge cock is opened, the tank emptied and the upper half falls, raising the lower one. The speed can be regulated by the valves, and, to prevent the danger of any sudden impact in closing or opening, buffers are attached.

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General Arrangement of the Structures.

The local by-laws regulate to a certain extent the details of construction of different classes of buildings, and as they are different in each town it would be impossible to lay down any definite rules. Many of these by-laws however, are capable of very elastic or vague interpretation, for while the Liverpool Exchange Company considered it necessary to obtain a special Act of Parliament in order to use the Fox and Barrett flooring in its new buildings on account of the by-laws, which state that the roofs of fire-proof rooms "shall be entirely covered with an arching of brick and mortar not less than nine inches thick, or with flags and stones, etc.," the last phrase, "with flags and stones," is now held to be sufficient to allow the adoption of other systems. Another curious rendering of the by-laws was the subject of litigation in November 1890, when the surveyor of East Kensington summoned Messrs. J. W. Hobbs & Co., for an alleged breach of the Metropolitan Building Act, by fixing a wooden surface to the concrete and iron floors of the lobbies of Albert Gate Mansions, whereas the Act specifies that such floors "shall be of stone or other fire-proof material." The Bench very properly refused a case, and dismissed the summons.

As the ventilation of a building is of as much importance as the fire-proof construction, it must be remembered that air-shafts are are also good channels for conducting flame, sparks, or smoke, from one part of a building to another, and also for supplying air to feed the flame. All such shafts, therefore, should be so constructed that communication from the various floors can be easily cut off. For the same reason, the entrances to hoist shafts should be fitted with fire-proof doors under easy control. Stair shafts should be built outside the main building and not enclosed; this however is not often practicable, except in the case of mill construction. If the stairs are in the interior of a building, the shaft should be entirely of brickwork or other fire-proof material with fire-proof doors at each landing.

As many deaths are caused by suffocation from smoke before the actual flame reaches the victims, it is essential that the means of egress should be large, especially in a theatre, where there is a great concentration of people. Inclined planes should be adopted instead of steps, and the leads should be as direct as possible. Large rooms in mills and warehouses should, where practicable, be subdivided into compartments by light partition walls of fire-proof material.

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General Conclusions.

The question of the causes, the prevention and the extinction of fires is beyond the scope of this Paper, and is of sufficient interest to form an independent communication.

For mills and warehouses, mansions with valuable furniture and pictures, public offices, infirmaries and hospitals, fire-proof construction should undoubtedly be adopted; and taking into account the number of fires and the great loss of life annually—in London alone in 1890 there were 2,555 fires with 61 fatal results—the by-laws should be made more stringent. For less pretentious dwelling houses and buildings, the construction may at a slight extra cost be made sufficiently fire-proof to prevent fire from spreading, and thus to enable the inmates to escape and to remove some of the goods and furniture. As a result of the consideration of the various fire-proof materials and modes of construction, the Author has arrived at the following conclusions:—

Of actual building materials, previous experiences and the experiments of the Author have shown conclusively that fire-brick offers the greatest resistance to the action of fire, and should be used wherever practicable for internal walls and piers; that of the stones, granite offers the least resistance, often failing at a moderate temperature, and the sandstones offer the greatest. No stone however should be used constructionally internally, but only for ornamental purposes. Although the results of the experiments carried out by the Author upon the various concretes are not offered as being scientifically accurate, they are sufficiently approximate to enable a fair opinion to be formed of their value for fire-proof construction. The tests of the materials after heating and quenching are unsatisfactory, inasmuch as the results are far from uniform. The briquettes were, comparatively speaking, small, and it was impossible to heat and quench them under exactly the same conditions; the change in their qualities, however, was so marked, that if only the minimum reduction of strength in each case were taken, the result would be very unfavourable in most cases. It may be agreed that the reduction in strength was caused wholly by the quenching, and that experiments should also have been made with a set of briquettes after being heated only; but these are not the conditions under which the material is treated in a conflagration, where it has to be submitted to the action of both fire and water, and therefore the knowledge of how it will withstand fire alone is not of much

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value. The neat cement was reduced in strength 60 per cent. by the heating and quenching, the addition of sand increasing the percentage of loss considerably. The mixture of cement and fire-brick suffered less than the neat cement. The mixture of plaster of Paris and furnace slag gave a strong concrete under normal conditions, but after heating and quenching it was practically useless. The mixture of plaster of Paris and fire-clay gave a fairly strong block at ordinary temperature, but was useless, after heating and quenching. Taken as a whole, the cement concrete stood the test better than the plaster of Paris concretes, but none of them can be considered satisfactory. The best material for floors, roofs, and walls is undoubtedly fire-brick, and where great strength is not required, as in column-casing, ceilings, wall-furring, &c., porous terra-cotta may also be used with advantage. The flat floors of concrete, made by Messrs. Dawnay, Homan and Rodgers, Measures, and others, are light and strong, have the advantage of being shallow, and are cheap in construction, while the weakening action of fire and water on the material is minimized by the short span of the slabs. The combination floors of concrete, resting on hollow tiles, as adopted for the Liverpool "Flags" and recently by Messrs. Fawcett, Homan and Rodgers, and other makers, are good, and although not quite so strong for floors of equal depths as those of the flat homogeneous concrete system, are more fire- and water-proof. The best fire- and water-proof flooring is the hollow-brick or tile system, of which there are many excellent forms, either with curved or flat soffits. Whether curved or flat arches are used, it is advisable to employ tie-bars (which must be encased in the brickwork), for the joists, for it is not safe to trust to the weight of the walls to withstand the thrust.

The question of cost of the different systems of flooring has purposely not been considered; for although it is advisable to know what the cost of a certain system may be, published prices are often very misleading. One floor may be quoted as costing less per square foot than another, but it is difficult to specify what this price includes, and it is possible for a cheap floor to cost more when completed than one quoted at a higher price. The length of the required spans may also possibly reverse the costs of various floors. As a rule, therefore, prices per square yard are very misleading, and it is far better to obtain estimates for each particular requirement. Flat concrete arches are, however, in all cases cheaper than hollow-brick floors, but they have not the same advantages; as an approximate estimate, the prices of the former

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system may be taken at about seven shillings, and of the latter at about nine shillings per square yard.

In no case should any constructional ironwork be exposed; the girders and joists are covered in by the system just referred to, and it is absolutely necessary for the columns to be equally protected. Hollow-bricks and tiles of fire-clay or porous terra-cotta form the best protection, and if plaster or concrete be used, it should be with either Johnson's or Golding's wire and iron lathing, Dennett's corrugated strips, or other approved plan for forming an efficient key. The columns should never be sandwiched with the beams, but should be continuous throughout. Wherever plaster or cement is used for ceilings, partitions, &c., it should have some efficient key similar to those recommended for the columns. Partitions should be as frequent as practicable, and constructed preferably of hollow tiles or bricks of fire-clay or porous terra-cotta. The solid timber construction of Messrs. Evans & Swain, and that known as the "American Mill" or "Slow Combustion" system, while not absolutely fire-proof, form an admirable protection against the spread of fire; confining it in most cases to the section of the building in which it originated. Roofs should be flat wherever practicable, as it is easier to lay a ceiling on the fire-proof system, than to protect from fire the members of trussed principals.

In conclusion, the Author wishes to acknowledge his indebtedness to the various English and American engineers and manufacturers who have supplied him with much valuable information, to Professor H. S. Hele-Shaw for the use of his testing machines, and to Mr. Thos. Morris, of Warrington, for assistance and facilities offered when testing the stones.

The Paper is accompanied by several tracings, from which the *Figs.* in the text and Plates 5, 6 and 7 have been prepared.

[APPENDIX.

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APPENDIX.

TABLE I.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	Neat Cement . . .	1	124·6	565	..
2	,, ,, . . .	1	124·6	520	..
3	,, ,, . . .	1	124·6	520	..
4	,, ,, . . .	1	124·6	564	..
5	,, ,, . . .	1	124·6	604	..
6	,, ,, . . .	1	124·6	..	100
7	,, ,, . . .	1	124·6	..	212
8	,, ,, . . .	1	124·6	..	76
9	,, ,, . . .	1	124·6	..	98
10	,, ,, . . .	1	124·6	..	100
			Average	554·6	117·2

Average loss of strength after heating and quenching, 60·8 per cent.

TABLE II.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 1 Sand .	1	120·9	476	..
2	,, ,, .	1	120·9	464	..
3	,, ,, .	1	120·9	358	..
4	,, ,, .	1	120·9	520	..
5	,, ,, .	1	120·9	422	..
6	,, ,, .	1	120·9	..	188
7	,, ,, .	1	120·9	..	52
8	,, ,, .	1	120·9	..	50
9	,, ,, .	1	120·9	..	82
10[1]	,, ,, .	1	120·9	..	..
			Average	117·2	93

Average loss of strength after heating and quenching, 20·6 per cent.

[1] Damaged before testing.

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TABLE III.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 3 Sand .	1	111·2	102	..
2	,, ,, .	1	111·2	108	..
3	,, ,, .	1	111·2	84	..
4	,, ,, .	1	111·2	110	..
5	,, ,, .	1	111·2	100	..
6	,, ,, .	1	111·2	..	12
7	,, ,, .	1	111·2	..	18
8	,, ,, .	1	111·2	..	12
9	,, ,, .	1	111·2	..	33
10[1]	,, ,, .	1	111·2	..	..
			Average	100·8	18·7

Average loss of strength after heating and quenching, 81·4 per cent.

[1] Damaged before testing.

TABLE IV.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 5 Sand .	1	109·7	54	..
2	,, ,, .	1	109·7	62	..
3	,, ,, .	1	109·7	47	..
4	,, ,, .	1	109·7	66	..
5	,, ,, .	1	109·7	144	..
6	,, ,, .	1	109·7	..	16
7	,, ,, .	1	109·7	..	14
8[1]	,, ,, .	1	109·7	..	..
9	,, ,, .	1	109·7	..	..
10	,, ,, .	1	109·7	..	..
			Average	74·6	15

Average loss of strength after heating and quenching, 79·8 per cent.

[1] Damaged before testing owing to their soft condition.

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TABLE V.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 4 Slag	2·25	163·08	111·1	..
2[1]	,, ,,	2·25	163·08	..	..
3	,, ,,	2·25	163·08	102·2	..
4[2]	,, ,,	2·25	163·08	..	..
5	,, ,,	2·25	163·08	111·1	..
6	,, ,,	2·25	163·08	..	22·2
7	,, ,,	2·25	163·08	..	21·2
8	,, ,,	2·25	163·08	..	24·4
9	,, ,,	2·25	163·08	..	22·2
10	,, ,,	2·25	163·08	..	25·3
			Average	108·1	23·06

Average loss of strength after heating and quenching, 69·3 per cent.

[1] Broken in adjusting machine.

[2] Broken in adjusting machine.

TABLE VI.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 4 Firebrick	2·25	95·04	71·1	..
2	,, ,,	2·25	95·04	80·0	..
3	,, ,,	2·25	95·04	93·3	..
4	,, ,,	2·25	95·04	93·3	..
5[1]	,, ,,	2·25	95·04	..	..
6	,, ,,	2·25	95·04	..	30·2
7	,, ,,	2·25	95·04	..	31·1
8	,, ,,	2·25	95·04	..	37·7
9[2]	,, ,,	2·25	95·04	..	..
10	,, ,,	2·25	95·04	..	23·1
			Average	84·4	30·5

Average loss of strength after heating and quenching, 50·9 per cent.

[1] Broken in adjusting machine.

[2] Broken in adjusting machine.

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TABLE VII.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 4 Pumice	2·25	64·8	88·8	..
2	,, ,,	2·25	64·8	75·5	..
3	,, ,,	2·25	64·8	88·8	..
4	,, ,,	2·25	64·8	111·1	..
5	,, ,,	2·25	64·8	108·8	..
6	,, ,,	2·25	64·8	..	62·2
7	,, ,,	2·25	64·8	..	21·7
8	,, ,,	2·25	64·8	..	42·6
9	,, ,,	2·25	64·8	..	38·6
10	,, ,,	2·25	64·8	..	26·6
			Average	94·58	38·3

Average loss of strength after heating and quenching, 59·5 per cent.

TABLE VIII.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Cement; 4 Coke Breeze	2·25	71·65	44·4	..
2	,, ,,	2·25	71·65	88·8	..
3	,, ,,	2·25	71·65	71·1	..
4[1]	,, ,,	2·25	71·65	..	..
5	,, ,,	2·25	71·65	75·5	..
6	,, ,,	2·25	71·65	..	22·2
7[2]	,, ,,	2·25	71·65	..	31·3
8	,, ,,	2·25	71·65	..	26·6
9	,, ,,	2·25	71·65	..	40·0
10	,, ,,	2·25	71·65	..	30·2
			Average	69·9	30·06

Average loss of strength after heating and quenching, 57·1 per cent.

[1] Broken in adjusting lever. [2] Fractured in two places simultaneously.

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TABLE IX.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Plaster of Paris; 4 Firebrick . . .	2·25	89·6	75·5	..
2	,, ,,	2·25	89·6	84·4	..
3	,, ,,	2·25	89·6	44·4	..
4	,, ,,	2·25	89·6	55·5	..
5	,, ,,	2·25	89·6	75·5	..
6[1]	,, ,,	2·25	89·6	..	19·1
7	,, ,,	2·25	89·6	..	8·0
8	,, ,,	2·25	89·5	..	4·0
9[2]	,, ,,	2·25	89·6	..	..
10[3]	,, ,,	2·25	89·6	..	..
			Average	66·8	10·3

Average loss of strength after heating and quenching, 75·5 per cent.

[1] Peculiar fracture, see *Fig. 2* in text. [2] Too soft to test. [3] Too soft to test.

TABLE X.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	1 Plaster of Paris; 4 Pumice	2·25	55·6	57·7	. ..
2	,, ,,	2·25	55·6	65·5	..
3	,, ,,	2·25	55·6	62·2	..
4	,, ,,	2·25	55·6	44·4	..
5[1]	,, ,,	2·25	55·6	..	..
6[2]	,, ,,	2·25	55·6	..	4·0
7	,, ,,	2·25	55·6	..	1·7
8	,, ,,	2·25	55·6	..	1·7
9	,, ,,	2·25	55·6	..	6·2
10[3]	,, ,,	2·25	55·6	..	..
			Average	57·4	3·4

Average loss of strength after heating and quenching, 94·7 per cent.

[1] Damaged before testing. [2] Peculiar fracture, see *Fig. 2* in text.
[3] Damaged before testing.

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TABLE XI.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	{1 Plaster of Paris; 2 Slag . . . .}	2·25	148	240·0	..
2	,, ,,	2·25	148	222·2	..
3[1]	,, ,,	2·25	148	..	..
4	,, ,,	2·25	148	208·8	..
5[2]	,, ,,	2·25	148	..	..
6	,, ,,	2·25	148	..	1·6
7	,, ,,	2·25	148	..	2·1
8	,, ,,	2·25	148	..	5·1
9	,, ,,	2·25	148	..	10·1
10[3]	,, ,,	2·25	148	..	..
			Average	223·3	6·9

Average loss of strength after heating and quenching, 96·8 per cent.

[1] Broke in adjusting machine. [2] Broken before testing.
[3] Broken before testing.

TABLE XII.

No. of Test.	Proportions of Concrete.	Sectional Area of Briquette in Square Inches.	Average Weight per Cubic Foot in Lbs.	Breaking Weight in Lbs. per Square Inch at 60° Fahrenheit.	Breaking Weight in Lbs. per Square Inch after being Heated and Quenched.
1	{1 Plaster of Paris; 2 Firebrick . . .}	2·25	106·9	173·3	..
2	,, ,,	2·25	106·9	173·3	..
3	,, ,,	2·25	106·9	146·6	..
4	,, ,,	2·25	106·9	197·7	..
5	,, ,,	2·25	106·9	146·6	..
6[1]	,, ,,	2·25	106·9	..	8·0
7	,, ,,	2·25	106·9	..	14·6
8	,, ,,	2·25	106·9	..	11·1
9	,, ,,	2·25	106·9	..	21·7
10	,, ,,	2·25	106·9	..	23·1
			Average	167·5	15·7

Average loss of strength after heating and quenching, 90·0 per cent.

[1] Peculiar fracture shown full size in *Fig. 2* in text.

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(*Paper No. 2525.*)

"The North Sea-Wall and Royal Albert Drive, Scarborough."

By WHATELY ELIOT, M. Inst. C.E.

FOR many years the attention of the authorities at Scarborough has been, from time to time, directed to the inroads of the sea upon the cliffs in the North Bay, and to the necessity of constructing some protective works; but no definite steps were taken until the end of 1879, when a most serious landslip took place, carrying with it a portion of the road and footpath facing the houses at the top of the cliff. This occurrence aroused the local authorities to the necessity for immediate action. Considerable sums of money had already been expended on the north shore, mostly by private enterprise, in roads, tramway, iron pier, and other works; and there was a large amount of valuable property on the top of the cliff, consisting of houses, hotels, &c., which were all endangered by the continual slipping of the cliff. In 1881 the construction of a carriage-way round the base of the Castle Hill, connecting the north and south bays, was proposed. Meanwhile, further heavy slips took place; and in 1882 the Corporation, having already taken steps to purchase the undercliff, instructed their Borough Surveyor to prepare plans for the construction of a sea-wall and road at the base of the cliffs. The scheme was submitted to Sir John Coode, President Inst. C.E., who reported in June, 1883, that it presented financial rather than engineering difficulties, and that if carried out as proposed in the report, the works would fully answer the requirements. Much delay subsequently occurred in negotiations before the Corporation could acquire the property. Meanwhile the sea continued making encroachments; and at last, at the beginning of 1886, it was decided to protect the cliffs of the north bay, from Peasholm to the Castle Holms, by the construction of a sea-wall and promenade (Plate 8, Fig. 1), the Author being selected to design and superintend the works. Although the scheme included the drainage and laying out of the cliffs, these works were postponed until the sea-wall was well advanced. This Paper therefore only deals with the works of the sea-wall, promenade, and drive.

Sea-Wall.—The wall is 3,600 feet long, and its face is formed to

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a curved profile having a radius of 17 feet, the level of the coping being 13 feet above high water spring tides (Plate 8, Fig. 2). It is founded throughout upon hard shale, being carried down 2 feet below the surface of the shale. The thickness of the wall is 5 feet at the top, increasing to 16 feet at the base, which is at an average level of 9 feet below high-water spring-tides. The face of the wall consists of small blocks of Portland cement concrete, composed of 1 of cement to 6 of shingle and sand, the proportions of shingle to sand being about 4 to 2. The blocks were cast in moulds with the face upwards, a chamfer of 1¼ inch in width being formed round the face of each; and the face, for at least 2 inches in depth, was formed of 2 parts of fine shingle passed through a ¼-inch sieve, and 1 part of Portland cement, no fine sand being used for this purpose. The face of each block was formed at the same time as the block itself, so that the two qualities of concrete should form one substance. The blocks were kept a month before they were set in the wall. In the lower five courses, they were made as shown (Plate 8, Fig. 5), with a groove formed in the back, 6 inches wide by 3 inches deep, and were set in the work so that the grooves should lie transversely to the length of the wall. The object of the grooves was to form a bond with the concrete at the back, and the result proved most satisfactory. The face blocks above the five lower courses (Plate 8, Figs. 3 and 4) were laid in courses, 1 foot thick, with header and stretcher alternately. The blocks were set in 2 to 1 Portland cement mortar, the joints being well grouted. No machinery was required for setting them, two men being able to carry a block on a hand-barrow, and to lift it into its place on the wall. As the blocks were set, they were backed up to the height of two courses at a time for the full thickness of the wall, with concrete composed of 5½ parts of rough shingle and 2½ parts of sand to 1 part of Portland cement, with pieces of rough stone or rock embedded in it. The coping of the wall, 1½ foot thick, was formed *in situ* with similar concrete to the hearting of the wall, the top edge being rounded to a radius of 6 inches; and a substantial iron hand-railing was fixed on it. The mixing was done by hand on movable planked staging, as the work was distributed over such a length of ground that the amount of concrete required per lineal foot of wall was only about 4½ cubic yards. The shingle and sand for the concrete were obtained chiefly from the foreshore. The blocks in the face of the wall above high water were not at first provided with a special facing; but at times the foreshore got piled up against the face of the wall above the level of high-

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water, and scoured the surface of some of these blocks, so that subsequently they were specially faced for the whole height of the wall. The foreshore consisted of a layer of sand and gravel, varying from 5 to 2 feet thick, overlying shale; and occasionally during rough weather the shale was left quite bare in parts. The cement used in the work was of the best quality, specified not to weigh less than 112 lbs. per striked bushel, and not to leave a greater residue than 10 per cent. after passing through a sieve of two thousand five hundred meshes to the square inch. Test bricks, placed in water twenty-four hours after gauging, had to stand, seven days after gauging, a tensile strain of 330 lbs. per square inch. The cement was not allowed to be used until it had been stored in bulk for four weeks in properly constructed sheds. The line of the wall, as constructed, was about 70 feet from the base of the cliff, following the general contour of the bay. As the site was at half-tide level, all the work below the level of high-water was tide-work. At neap tides, however, if the sea was not rough, the tide was easily excluded by raising a bank of sand in front of and around such portions of the wall as were under construction. The greater part of the foundations were thus constructed at neap tides, in sections from which the tide was excluded by sand-barriers, the water inside the barriers being kept down by means of hand-pumps. As a rule, nearly a week at a time could be depended on for building the lower portions of the wall, so that such a length of trench was opened out and protected with sand-barriers as it was found by experience could be dealt with during each period of neap tides. The foundation courses for this length were laid, and the wall raised to the level of high-water neap tides, and then left till the following neap tides, when it could be raised without the necessity of erecting another barrier of sand, the former barrier having been destroyed by the sea during spring tides. At spring tides, the construction of the upper portion of the wall was proceeded with. Periodical delays from rough seas naturally occurred; but the actual damage to work in course of construction was very small, considering the exposure of the coast, and the sudden storms to which it is subject.

Road and Promenade.—As the wall was constructed, the space between it and the cliff was filled in with clay, stones, and other material, obtained from the face of the cliff; and after this had become thoroughly consolidated, the surface was formed for a road 40 feet wide, and a footway 30 feet wide. The surface of the filling under the road was formed of a 6-inch layer of stones, on which was placed a layer of gravel to receive the top surface of

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macadam asphalt. The surface of the promenade, or footway, was also prepared with brick rubbish to receive the tar pavement. These top surfaces of macadam asphalt and tar pavement were formed like most of the streets and footpaths in Scarborough. For the tar pavement, the ground was first prepared with a covering of brick rubbish, or broken stone, about 3 inches thick and well rammed down, allowing no clay to remain on the surface. The first layer[1] was then laid on, 1½ inch thick, and well rolled and rammed. The top layer[2] was then applied, so as to be ⅝ inch thick when finished, and well rolled, after which a sprinkling of Derbyshire spar was laid on and rolled to an even surface. The cost of the footway thus prepared was about 7*d.* per superficial yard. The macadam asphalt for the road-surface was prepared as follows:—On the surface of the ground, already prepared with a covering of rough hand-packed stones, a 2-inch layer of rough gravel, prepared like the first layer of the promenade, was laid on and well rolled. Then about 1½ inch of hard metal, slightly sprinkled with tar, was put on and rolled. The next layer was composed of the best hard metal, broken small enough to pass through a 1¼-inch wire screen, and treated in the same way as the first layer, and it was well rolled. The top layer was then laid on, being prepared and applied in a similar way as for the promenade. The cost of the road thus prepared was about 1*s.* 9*d.* per superficial yard.

Slipways and Steps.—Two slipways were constructed to give access to the sands, one at the extreme north end of the wall, and the other a short distance north of the iron pier. In addition to these slipways, there are three sets of steps leading from the promenade down to the sands. Numerous seats have been provided along the whole length of the promenade, some of them

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[1] To prepare this layer, gravel, passed through a 1¼-inch wire screen, was laid in a heap about a foot thick; several fires were made on the top of the heap, and covered over with refuse gas-cinders, to cause the heat to strike downwards, so as to completely evaporate all moisture from the gravel, and this was continued until the whole heap was covered with cinders. The heap was then turned over with a shovel, and gas-tar sprinkled on while the gravel was warm and being turned over. This was repeated until the gravel had received a sufficient coating of tar.

[2] For the top layer, a mixture of fine ashes and gravel, passed through a ⅜-inch wire screen, was spread on the ground, 6 inches thick with 6 inches of gravel on the top, and fires kindled, as in the preparation of the first layer. Then the whole was again screened, so as to take out the gas-cinders which were used for heating. The residue was then mixed with tar in the same manner as the first layer.

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being under the shelter of the cliffs at the back of the road.

Drainage of Surface-Water.—To take the surface-water from the road, and from the paths of the slopes at the back of the road, a 12-inch stoneware pipe was laid along the whole length of the road, on the side nearest the cliff, with a fall of 1 in 250 northwards and southwards from the iron pier. At the north end it discharges into a main sewer from the town, which is carried along the base of the cliffs to the north end of the bay. At the south end the drain discharges on to the shore at the extreme end of the sea-wall. Flood overflows were constructed at intervals, which discharge through the sea-wall on to the foreshore. Trapped gullies are provided close to the curb of the promenade, and connected with the drain by 6-inch stoneware pipe-drains.

Approach to the Iron Pier.—As the entrance to this pier is 11 feet above the surface of the new drive, it was necessary to form a slope on each side of it, with a gradient of 1 in 30, to bring the road up to the level of the approach to the pier. At the foot of these slopes the promenade was divided, half the width continuing at the same level as before, and half following the same gradient as the road, the two halves being joined by a flight of steps close to the pier on each side. By this method the coping of the sea-wall was kept at the same level throughout; and the raised part of the road and promenade were provided with a retaining-wall built 14 feet back from the face of the sea-wall. This wall was built of concrete, with a facing of sandstone ashlar. Where the new road reaches its highest level, opposite the entrance to the pier, it is widened out, and is connected with the road which formerly formed the approach to the pier and sands from the top of the cliff.

Effect on the Foreshore.—During calm weather the sea-wall causes the sand to accumulate in front to the level of high water of spring tides, and sometimes 2 or 3 feet above it, so that at neap tides, during calm weather, the sea does not reach the wall in places for some days; but during rough weather the sand is scoured away very rapidly immediately in front of the wall, and frequently the shale at the base of it is laid bare for some distance. Altogether, the wall has not had an injurious effect upon the foreshore, nor has it at all affected the sands as regards their suitability for bathing purposes; while, on the other hand, a fine promenade and drive have been provided, with easy access from the grassy slopes of the cliffs at its back.

Cost of Works.—The wall was commenced in November, 1886,

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the contract being let to Mr. W. C. Malton, of Scarborough, for the whole of the work,[1] with the exception of asphalting the surfaces of the road and promenade, for the sum of £17,168. This was increased by certain additions during construction to £18,777.

The work was completed in 1890, and opened by H.R.H. the Duke of Clarence and Avondale on June 27, 1890. The Author, on being appointed Resident Engineer of a section of the Manchester Ship Canal, resigned charge of the work in December 1887, by which time the sea-wall was in an advanced state. Mr. R. Aytoun, Assoc. M. Inst. C.E., succeeded to the charge of the works, which he retained till their completion.

A tracing accompanies the Paper, from which the illustrations in Plate 8, relating to the sea-wall and drive, have been taken.

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[1] *Quantities of Work.*

Excavation in shale for foundation . . .	3,330 cubic yards.
Concrete blocks in face of wall	3,292 „ „
Concrete hearting of wall	17,120 „ „
Filling at back of wall	115,770 „ „
Preparing surface for road	20,100 square yards.
„ „ promenade . . .	9,160 „ „
Stoneware pipe-drain, with connections, &c.	1,200 lineal yards.
Paving surface of slipways	2,300 square yards.

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(Paper No. 2524.)

"Securing the North Cliff, Scarborough."

By ROBERT AYTOUN, Assoc. M. Inst. C.E.

THE northern extremity of Scarborough stands upon land from 100 to 175 feet above sea-level, which after falling abruptly to the sea-beach, forms the North Cliff and Undercliff, and skirting the North Bay for about ¾ mile. The cliff was subject to extensive slips, and the undercliff to erosion by the sea.

The construction of the sea-wall described by Mr. W. Eliot, M. Inst. C.E.,[1] has secured the undercliff at that part from the sea; and during its progress, the Corporation employed men in draining, laying out, and securing the cliff and undercliff, at first under the superintendence of Mr. Leonard Thompson; and from January 1889 under the Author, as regarded works for preserving the cliff.

The rocks of the north cliff and undercliff belong to the middle and lower oolites. The main bulk of the undercliff from A to C (Plate 8, Fig. 1) consists of shale, mingled at intervals with irregularly bedded masses of sandstone. Above this lies a quantity of débris, from 10 to 30 feet thick, which has fallen or slipped from the adjacent cliff. The cliff, rising behind at varying elevations, is composed of boulder clay from B to D (Plate 8, Fig. 1), underlaid by the same estuarine rock as the undercliff (Plate 8, Figs. 8 and 9). From B to A it consists of sandstone, below which is a bed of shale covering a band of hard limestone—cornbrash—in all about 10 feet thick; and below the cornbrash is the upper estuarine series, of great depth, and forming the foundation of the whole cliff and undercliff (Plate 8, Figs. 6 and 7). The distinction between cliff and undercliff is less marked in the boulder clay, from B to D, than in the sandstone section, where the difference culminates at A in a precipice 120 feet high.

The north cliff and undercliff were exposed to the following destructive agencies:—

1. The erosion of the shale foundation of the undercliff by the sea.

2. The infiltration of water from rain or springs amongst the

[1] Minutes of Proceedings Inst. C.E., *ante*, p. 289.

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loose débris on the undercliff, leading to disintegration of the mass and slips on the shale base.

3. The dipping of the surface of the underlying shale of the undercliff seawards, greatly facilitating slips.

4. The disintegrating action of atmospheric influences, especially frost, upon the exposed shales of the estuarine and cornbrash strata.

The measures adopted to arrest the work of destruction were as follows:—

1. The erosive action of the sea was prevented by the sea-wall skirting the base of the undercliff.

2. The loose saturated mass, forming the upper portion of the undercliff, was drained by a series of timbered trenches, 3 feet wide, cut through the clay or sandstone débris to a minimum depth of about 2 feet into the solid shale substratum. At the bottom of each trench, 4-inch stoneware pipes were laid; and the trench was filled with rubble to a height of 2 or 3 feet above the impervious shale. When, however, the material was very wet or specially liable to disturbance, the rubble was carried up to the top of the trench. These trenches were carried at right angles to the "trend" of the cliff, about 30 feet apart. The 4-inch pipes were led from the trenches down the face of the undercliff to a 12-inch main under the Albert Drive, or were joined, where practicable, into a 6- or 9-inch path drain, running diagonally down the face of the undercliff.

In the boulder-clay portion of the cliff, from C to B (Plate 8, Fig. 1), a longitudinal cutting was made in short lengths in the loose undercliff at the base of the cliff down to below the water-bearing beds, to prevent the percolation of water from the gravel beds in the cliff into the upper portion of the undercliff. Pipes were led up from the transverse drains already mentioned, and inserted in the solid cliff along the bottom of the cutting. Above the pipes, a rubble wall or screen, 18 inches wide at the base and 9 inches at the top, was packed against the side of the cliff; and the loose material of the undercliff was then banked against it, forming a buttress to the cliff and a protection against atmospheric destruction. The screen of rubble protected the made bank effectually from infiltration from the cliff, and also from the action of surface water from above.

3. At several places in the undercliff, however, the inclination of the surface of the shale, underlying the disintegrated mass of undercliff, together with a lubricating film formed on the surface of the shale, which was not affected by drainage, promoted a slow

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but continuous motion seawards of the superincumbent mass, which it would have been most hazardous to attempt to arrest by retaining walls founded on the precarious shale base. Timbered pits, averaging 22 feet in length transversely and 12 feet wide, were accordingly sunk down to the shale, which was then cut into benches in the solid, dipping landwards about 1 in 6. Drain pipes were laid along the low edge of each bench, and connected with the deep transverse drains mentioned above. The benches were next covered with 1 to 2 feet of dry rubble, and the pit refilled with excavated material. The retaining bank thus created by a succession of pits distributed the pressure on the foundation far more than would have been possible with a wall; making it least at the front edge of the undercliff, where there was most danger of a fracture of the shale foundation. In two places a greater depth of stone was placed upon some of the benches, and packed by hand in the front of the bank. This was rendered necessary at Z Z (Plate 8, Figs. 1 and 9), on account of the small base of the undercliff, and at Y Y (Plate 8, Figs. 1 and 8), by the special persistency of the sliding movement. On the site of the old "Rock Gardens" (Plate 8, Fig. 7), the benching was much facilitated by the removal of a great part of the material above the area to be benched for filling behind the sea-wall. The areas of shale benched in this way amounted to about 3,500 square yards.

4. The disintegration of the exposed shale by atmospheric influences was prevented by covering it, where practicable, with sods, secured in position by small wooden pegs. At the base of the sandstone cliff, however, the face of the cornbrash and lower shales fell so precipitously towards the undercliff that the exposed shale had to be covered with a screen of stones, against which the débris of the undercliff was banked up, and sodded or sown (Plate 8, Figs. 6 and 7).

The works were completed in June 1890; and the area of undercliff thereby rendered available for public use, on the north side of Scarborough, is over 19 acres. The cost of the works, exclusive of excavation for filling behind the sea-wall, and of property rights purchased by the Corporation, was rather over £12,000.

The Paper is accompanied by three tracings, from which the sections of cliff in Plate 8 have been reduced.

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(*Students' Paper No. 280.*)

"The Lanarkshire and Ayrshire Railways."[1]

By WILLIAM ARCHER PORTER TAIT, B.Sc., Stud. Inst. C.E.

(*Abstract.*)

AN Act for the Barrmill and Kilwinning Railway was obtained in 1883; and extensions of the scheme to Ardrossan, Kilbirnie, and Irvine, were authorized in 1884, owing to an agreement with Lord Eglinton to extend and improve his harbour at Ardrossan, and the desire of the Lanarkshire coalmasters to obtain a fresh outlet for their coal (*Fig. 1*). These railways, situated wholly in Ayrshire, have a total length of 21 miles, of which 14 miles are double line; and the Engineer-in-Chief was Mr. John Strain, M. Inst. C.E. The bridges, about one hundred in number, include a viaduct over the River Garnock, and three bridges under and four over the Glasgow and South-Western Railway.

On the Kilbirnie and Irvine branches, rubble concrete, composed of "irregular sized stones set and packed solid on all sides with concrete," was used for the foundations, abutments and piers of bridges, retaining walls, culverts, &c. The concrete, formed of cement, sand, and broken stones (1 to 5), was first deposited in a 6-inch layer at the bottom within timber-framing coated with soft soap; large rough stones, up to 2 tons, were then laid 3 inches away from the frame and from each other, and the intervals packed with concrete; and upon this course another 6-inch layer of concrete was deposited, followed by another course of stones, and so on; the concrete near the front boarding being specially rammed to form a smooth face. The progress at the ordinary bridges averaged from 12 to 15 cubic yards of rubble concrete daily; but at larger bridges, especially with a concrete mixer, the work done reached 20 or 25 cubic yards per crane per day. To maintain this rate in a similar bridge of rubble masonry, double the number of men would be required; but though skilled labour was to a great extent dispensed with, the cost of the rubble concrete nearly equalled that of rubble masonry, owing to the quantity of cement (1½ bags per cubic yard) used in the concrete. Weeping holes formed by 2-inch earthenware pipes inserted at intervals, served also during construction for the introduction of bolts tying

[1] This communication was read and discussed at a meeting of the Students on the 13th of March, 1891.

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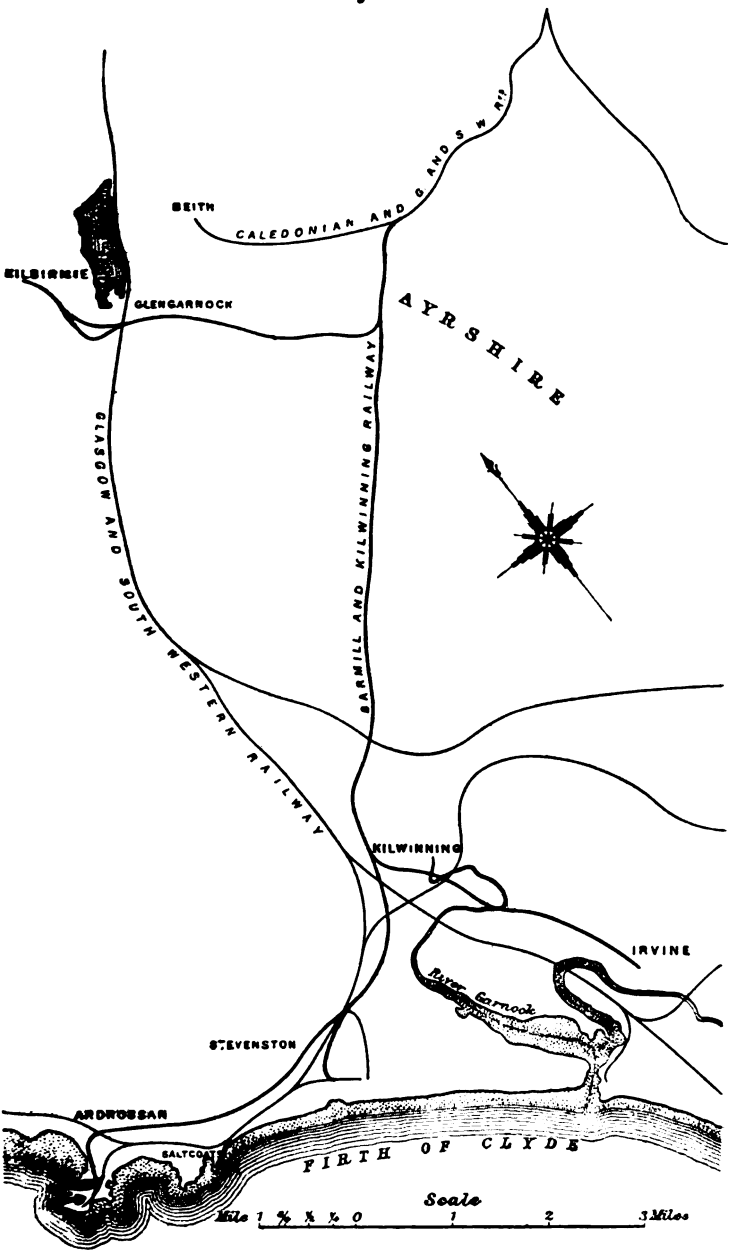
Fig. 1.



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together the framework, which was generally left on for two days after the completion of the work.

The viaduct over the River Garnock, having seven semicircular arches of 50 feet span, was built on a gradient of 1 in 65, and partly on a 30-chain curve, the rail-level being 70 feet above the river. Soon after its completion, a crack was observed in the northern abutment; and it was found that the abutment and the adjacent pier had settled, whilst the next pier, which was standing on rock had remained firm; and a forward movement of the abutment and first pier had contracted the second span, causing the arch to rise about 5 inches at the crown. After ineffectual attempts to depress the crown of this arch, by weighting it with 200 tons of rails, and by sawing through the bed joints at the keystone, inverts were laid between the piers across the first three spans, in the form of ribs 4 feet wide in the first two, and solid in the third across the river, which stopped the movement. The spaces in the haunches, moreover, were filled with concrete; and a bed of concrete, 2 feet thick, was laid over the first three arches.

Advantage was taken of the cessation of traffic on the Glasgow and South-Western Railways on Sundays, to obtain twenty-four to thirty hours at a stretch for work connected with the construction of the bridges crossing that railway. About three Sundays were required for driving the piling and erecting the staging for over-bridges carrying the railway temporarily, and allowing the passage of the service line underneath. In one of these three bridges, a service line was not needed, so that two 12-inch by 12-inch balks bolted together sufficed to carry each rail over the trenches in which the abutments were built. The steel main girders, cross girders, and buckle plates, were riveted together on a staging near their final position, and parallel to the edge of formation; and on a Sunday this superstructure was substituted for the balks, and was run on rollers, placed under the main girders, over greased rails, and drawn into place by aid of two 3-ton winches, in about an hour and a half.[1] Owing to delay in the delivery of the steel-work for the Stevenston bridge, which was to cross over the three lines of the Glasgow and South-Western Railway at an angle of 28°, with a span on the skew of 107 feet, a temporary timber bridge had to be constructed for the service line. The span of this bridge was reduced to 45 feet by modifying the line of crossing to 65°, which necessitated the construction of approach curves of 120 feet radius. The two main girders, each 126 feet long and weighing

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 170.

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90 tons, were built on this temporary structure, and slewed separately into position by two 7-ton winches.[1] One girder had only to be pivoted round on a central cradle; the other was drawn along greased rails, and put into place in about four hours. The girders of one of the Kilbirnie bridges, crossing over a private railway, in two spans of 50 feet, were raised into position in four minutes by means of a pole, 37 feet high, steadied by four wire-rope guys, and fitted with tackle. The hoisting was effected by the engine which brought the girder on three trucks along the line underneath. Another Kilbirnie bridge, with a span of 61 feet on a gradient of 1 in 70, carries the railway over the main line and sidings of the Glasgow and South-Western Railway near Glengarnock. The main girders are 110 and 120 feet long, and weigh 70 tons. Each girder was built on staging erected on a vacant space, reserved for two additional lines, in front of the higher or east abutment, and carried back a sufficient distance behind. When the girder was ready for launching, two trestles running on bogies were drawn on to two sidings in front of the west abutment, and blocked up. Two bogies were then run under the jacked-up girder, one near its centre, and the other at its tail end, which was counterpoised with 10 tons. It was then drawn slowly over by a 3-ton steam crane, stationed behind the west abutment, till it got a bearing on a bogie placed on the trestles, which served as a temporary staging in front of the west abutment. The tail end of the girder was next jacked up, to allow the bogies on that side to be run back; and it was finally pulled over into position.

A large area of country seaward of the railway, near Stevenston, has been laid waste by blown sand travelling inland a few feet per annum. This has been arrested round the Ardeer dynamite factory by tree and grass planting. A strip of land seawards of the line, 100 feet wide, taken by the railway, is protected by a concrete fence wall, which, however, has been several times covered with sand, entailing much labour in removal.

The railways, including land, cost over £500,000, of which more than half was expended on works executed by Mr. Robert McAlpine of Glasgow. Mr. Donald A. Matheson, Assoc. M. Inst. C.E., was Mr. McAlpine's agent, and was assisted by the Author during two years.

The Paper is illustrated by a map, six tracings, three sketches in the MS., and a model, from the first of which the plan accompanying the text has been reduced.

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 201.

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OBITUARY.

SIR JOSEPH WILLIAM BAZALGETTE, C.B., Past-President, was born at Enfield on the 28th of March, 1819. The family was of French extraction, and the name figures in the fifteenth century among the old *noblesse*. His father was a Commander in the British Navy, from which, after much active service, he retired in 1815.

Having been educated in private schools, Joseph was articled at the age of seventeen to Mr. (afterwards Sir John) Macneill, and was employed at his recommendation as Resident Engineer on drainage and reclamation works in the North of Ireland. He subsequently directed his attention more particularly to this subject, and visited the principal works of that nature in Holland.

In 1842 he was practising on his own account in Great George Street, Westminster, and in 1845–6 was busily engaged in railway and other works of considerable magnitude, exerting himself to such an extent that his health suffered, and he was obliged to cease work and go into the country, where a year of perfect rest restored his energy.

On resuming business he accepted, in 1849, an appointment under the Metropolitan Commission of Sewers, and thus began his connexion with the two great municipal works by which his name has become so widely and so honourably known, namely, the Main Drainage of London and the Embankment of the River Thames. The best record of Sir Joseph's life and labours will, indeed, be formed by a brief history of these works, with which he was most specially identified from their inception to their successful completion.

Down to 1847 [1] the drainage of the Metropolis was under the charge of no less than eight separate municipal bodies, each exercising an independent sway over its own district. With such division it was impossible that any advantageous principles of drainage could be acted on, and the evils became so apparent that in 1848 an Act was passed to consolidate the whole management

[1] This account of the Main Drainage Works is taken from the published Report of the Royal Commission on Metropolitan Sewage Discharge, 1884.

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under one "Metropolitan Commission of Sewers." The Commissioners, an unpaid body of twelve gentlemen, began zealously to improve some details, but in 1849 they were superseded by a second body, which advertised for competitive designs for a complete systematic drainage of London. This body also resigned before the plans were examined, and their successors, among whom were included several eminent engineers, appointed an engineer of their own selection, Mr. Frank Forster, to prepare, partly in conjunction with Mr. Haywood, the Engineer of the City Commission of Sewers, a complete drainage scheme. This was done; and the scheme was described in two reports, dated respectively March 1850, and January 1851. The third Commission had, however, no power to carry out such works, and was superseded by a fourth, and this again gave way to a fifth, appointed late in 1852. Still, however, nothing practical ensued, and the Engineer, Mr. Forster, whose health had given way under the anxieties of his position, resigned his office, and shortly afterwards died.

At this time Mr. Bazalgette came prominently forward in the matter. He had since 1849 held office under the successive Commissions, and on the death of his chief he was selected, out of thirty-six candidates, as the most suitable person to fill the vacant post. He was immediately instructed, in conjunction with Mr. Haywood, to prepare a scheme for the main drainage, and the joint engineers, taking as a basis the proposals of Mr. Forster, presented a modified and improved plan in the early part of 1854.

The progress of this scheme was, however, frustrated by the interference of a public department called the General Board of Health, and after further changes in the Commission the Government resolved to create a new representative body, an Act to effect this object being passed on the 16th August, 1855. This was the origin of the Metropolitan Board of Works, one of whose first acts was to appoint Mr. Bazalgette as their Chief Engineer, and to instruct him to report at the earliest possible period as to the works necessary for the main drainage of the Metropolis.

It might be supposed that under these circumstances the work would henceforth go on smoothly; but this was not to be. It was a proviso in the Act that the designs of the Board were to be submitted for approval to the Government, and in accordance with this Mr. Bazalgette's plans were sent to Sir Benjamin Hall, the Chief Commissioner of H.M. Works, in June 1856. Questions were then raised about the outfalls and other details, and after the plans had been twice modified, the Government, being still dissatisfied, determined to refer the whole question to a Committee of three

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engineers, Captain Douglas Galton, R.E., Mr. James Simpson, and Mr. Thos. E. Blackwell. The submission was made in December 1856, and, after a long inquiry, the referees, in July 1857, reported on several points unfavourably to the Board's plan, and recommended a scheme of a much larger character. After some ineffectual negotiations the Board instructed Mr. Bazalgette, in conjunction with two other engineers, Mr. G. P. Bidder and Mr. Thos. Hawksley, to reconsider the matter. A reply, from these gentlemen jointly, to the Government referees was delivered in April 1858, and led to a discussion between the parties which lasted some time.

Meanwhile the state of the River Thames was daily becoming worse, and Parliament was in despair at seeing that nothing was being done. But there had been a change of Ministry, and, on the urgent application of the Metropolitan Board, Mr. Disraeli succeeded, in August 1858, in passing an Act which relieved them from the necessity of Government sanction, on the ground that, as the Metropolis paid for the works, they had a right to construct them in any way they pleased, or, as the First Commissioner afterwards expressed it, "He who pays the fiddler has a right to call the tune." This settled this matter. Immediately after the passing of the Act the Metropolitan Board instructed Mr. Bazalgette to complete the detailed designs, and contracts were entered into for the construction of the works. The engineer seconded their wishes most energetically. In 1865 the great drainage system was formally opened by H.R.H. the Prince of Wales; but the latter portions took considerable time, and it was not finally completed until 1875.

The works of the Metropolitan Main Drainage have been fully described in a Paper given by Mr. Bazalgette to the Institution in 1865, for which he was awarded a Telford Medal and Premium.[1] It will suffice here to say that they consisted of 83 miles of large intercepting sewers, draining more than 100 square miles of land covered with buildings, and estimated to deal with 420,000,000 gallons per diem. The amount expended on the works by the Board was £4,600,000.

As a conclusion to the remarkable history of this remarkable work it is only just to Sir Joseph's memory to insert the following observations by a body especially competent to judge of its merits, namely, the Royal Commission on the Metropolitan Sewage

[1] "On the Main Drainage of London, and the Interception of the Sewage from the River Thames," Minutes of Proceedings Inst. C.E., vol. xxiv. p. 280.

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Discharge, of which Lord Bramwell was President. In their First Report of 31 January, 1886, they say:—

"The historical notice we have given will show that the drainage system was decided on under great difficulties, the differences of opinion as to some of the principles of the scheme being very formidable. It became, therefore, an arduous task to settle the plans to be adopted, but the state of the river rendered a prompt decision necessary, and it cannot be questioned that the Metropolitan Board of Works had good grounds for the course they took in the matter. The arguments in favour of a larger scheme, with more distant outfalls, were urged with much force, and by very competent authorities, but the Board had to consider the important conditions of promptness of execution and economy of cost; and as they had reasonable justification for believing in the sufficiency of the scheme they adopted, they cannot be blamed for declining to commit their constituency to what they thought an unnecessary expenditure, especially as an extension of the outfall sewers to a lower point, if necessary, could always be effected at a future time; and, having once decided on their plans, the energy shown in carrying them out with all expedition is deserving of great credit.

"To their engineer also, who has been fortunate enough to see the great work carried through from its inception to its successful completion, high praise is due.

"It is true that the main features had been proposed before he took charge of the work, but this fact in no wise detracts from Sir Joseph Bazalgette's professional skill in re-designing the whole scheme, in all its comprehensive details, and in carrying it through all the intricate difficulties of its construction, so making that practical which before was theoretical only. And it must be observed that, whatever differences of opinion may exist as to disputed points in the design of the works, no question has ever been raised as to their excellence of construction.

"Then, further, no one can deny the great benefit that has arisen from the main drainage works. The discharge of the sewage into the river within the heart of London had become intolerable, and its interception has exercised a powerful influence in improving the general health of the metropolis. For the system has not only removed an offensive and deleterious element from the most populous part of London, but has also promoted general salubrity by improving the drainage of the entire metropolitan area.

"And even granting that some evils may be caused, as we think is the case, by the present mode of discharge, yet these are not of a nature to be compared with those that have been removed by the main drainage scheme."

In the latter years of Sir Joseph's engagement under the Board of Works, he designed and carried out extensive works to supplement the original main drainage scheme. These consisted chiefly in the enlargement of the existing sewage reservoirs at the main outlets at Crossness and Barking, and the construction of precipitating tanks, whereby the sewage sludge which had previously been accumulating in the bed of the Thames could be deposited in the tanks and pumped out into suitably constructed steam-vessels for rapid conveyance out to sea, where it would be discharged into deep water. In these large precipitating tanks

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the effluent sewage was also treated with chemical deodorants before it was permitted to be discharged into the river.

The other great work which has contributed to Sir Joseph Bazalgette's fame is the Embankment of the River Thames.

The idea of this had long been an object of contemplation with persons interested in the improvement and embellishment of the Metropolis. It was first propounded by Sir Christopher Wren after the great fire, and towards the middle of the present century, John Martin, the well-known painter, with remarkable foresight, devised a scheme for combining an embankment with the interception of the sewage from the river.

In 1860 the idea first assumed practical shape; an embankment was recommended by a committee of the House of Commons, and in the following year a Royal Commission concurred in the recommendation, but suggested that, in view of the magnitude and importance of the work, the undertaking should be entrusted to a body of special commissioners. The Metropolitan Board pointed out to the Government the inexpediency of calling into existence a new body for the purpose, particularly as the low-level sewer was to be formed in the embankment under their responsibility; the Government agreed with this view, and in 1862 passed an Act which empowered the Metropolitan Board to execute the work. This was followed by other Acts, the designs were prepared by Mr. Bazalgette and the work proceeded. Some delay was caused by the arrangement for constructing a large portion of the Metropolitan District Railway in connection with the embankment; and a portion of the eastern end near Blackfriars had to be modified accordingly, but by energy and good management the work was completed from Westminster to Blackfriars in 1870, and was opened in state by the Prince of Wales on the 13th of July in that year.

In 1866–9 another portion of the embankment was constructed on the Surrey side, between Westminster and Vauxhall, and in 1871–4 a further portion at Chelsea. In 1876 was formed the fine approach to the Embankment from Charing Cross, called Northumberland Avenue.

These admirable works, which cost £2,150,000, have been fully described in a Paper given to the Institution in 1878 by Sir Joseph's third son, Mr. Edward Bazalgette.[1]

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[1] "The Victoria, Albert, and Chelsea Embankments of the River Thames," of Proceedings Inst. C.E., vol. liv. p. 1.

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On the completion of this work the Queen was graciously pleased to confer the honour of knighthood on the Engineer who had previously (in 1871) been made a Companion of the Bath. The following was the letter conveying to the Board Her Majesty's command :—

10, Downing Street, Whitehall,
11th May, 1874.

Dear Colonel Hogg,—I have much gratification in informing you that, to commemorate the completion of the Thames Embankment, the Queen has been graciously pleased to confer on you the high distinction of a Knight Commander of the Bath (Civil Division), and on the eminent Engineer of the Works, already a C.B., the honour of Knighthood.

I remain, dear Colonel Hogg,
Yours sincerely,
(Signed) B. DISRAELI.

Colonel Hogg, M.P., Chairman of Metropolitan Board.

These monumental structures have not, however, been the only useful and important works designed and carried out by Sir Joseph in his capacity as Chief Municipal Engineer of the Metropolis.

Under the provision of the Metropolitan Toll Bridges Act 1887, Waterloo, Charing Cross, Lambeth, Vauxhall, Chelsea, Albert, Battersea, Wandsworth, Putney and Hammersmith bridges over the Thames, and the bridge at Deptford over the Creek, were purchased at a cost of nearly a million and a half, and opened to the public free of toll. Pending the enquiries to determine their value, Sir Joseph gave evidence as to their strength and condition, and, when they had passed into the hands of the Metropolitan Board, made important repairs and improvements in their structure. He also designed the new bridges at Putney and Battersea, and designed and constructed a steam ferry across the Thames between North and South Woolwich, which has been found of great public utility. He also raised the levels of all wharves along the banks of the Thames within the metropolis and of over 40 miles of river bank, so as to prevent the damage to property in the low-level districts which had been caused by the frequent overflowing at high tides.

Among the works designed by him but not yet carried out may be mentioned a large tunnel under the Thames between Greenwich and Blackwall, and a high-level bridge, consisting of a trussed steel arch of 850 feet span proposed to be erected over the river near the Tower.

He remained with the Metropolitan Board till its dissolution in 1889, and his last (thirty-third) annual report of the 31st of

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December, 1888, published in the final Official Report of the Board, gives an idea of the work he had to do. It occupies fourteen closely printed folio pages and refers to no less than nine hundred and fifty detailed reports he had made in the course of the year.

Sir Joseph was on many occasions consulted by foreign governments with reference to schemes for the drainage and improvement of large continental cities, and in his own country he frequently gave advice and assistance to the authorities of provincial towns.

Sir Joseph Bazalgette was connected with the Institution for more than fifty-three years, and at the time of his death only four members survived of older standing than himself. Entering as a Graduate on the 6th of March, 1838, he was transferred to the class of Member on the 17th of February, 1846. He was elected a Member of Council in December, 1867, a Vice-President in December, 1879, and filled the office of President in 1884. His Presidential Address was mainly devoted to considerations affecting public health and welfare in all the large cities of the world.

Sir Joseph married, in 1845, Maria, fourth daughter of the late Mr. Edward Kough, J.P., of New Cross, County Wexford, by whom he had a family of six sons and four daughters. Although of small stature and of somewhat delicate health, he possessed great energy and strength of will, which enabled him to combat and surmount the difficulties, often considerable, of his responsible public post. He had in later years often suffered seriously from asthma. He died, much regretted, at his residence at Wimbledon on the 15th of March, 1891.

JOHN MARLEY, youngest surviving son of Mr. Thomas Marley, of Middridge Grange, near Shildon, in the County of Durham, was born there on the 11th of November, 1823. He received his early education from the Rev. J. Birkbeck, of Denton, near Darlington. In March, 1840, he was articled to Mr. John A. Forster, of Bishop Auckland, a brother of the late Mr. Thomas E. Forster, M. Inst. C.E., passed subsequently under Messrs. George Hunter and William Longstaff at the Marquess of Londonderry's collieries, and finally completed his pupilage with Mr. Edward F. Boyd on the 30th April, 1844. He was soon afterwards appointed Lessor's Agent for some mineral estates in the County of Durham, and in October of that year was engaged under Mr. John Bourne in railway surveys between Newcastle and Berwick. Later in the same year he was employed at Whitehaven in getting up plans

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for the Whitehaven and Furness Railway. In 1845 he was engaged under Mr. John Dixon, the Engineer of the Stockton and Darlington Railway, in surveys for the Wear and Derwent Junction Railway, and, together with Mr. Thomas Bouch, in surveys for the Wear Valley Extension Railway. In October, 1846, he was appointed Manager of Woodifield Colliery by the young firm of Bolckow and Vaughan, and entering upon his duties on the 1st of November, 1846, remained with that firm until it was converted into a Limited Liability Company in 1864, when he was retained as Chief Mining Manager. He continued in charge until he resigned that appointment at the close of 1867, remaining, however, a Consulting Engineer of the Company for two years longer. During Mr. Marley's connection with the firm of Bolckow and Vaughan colliery was added to colliery, important winnings made, limestone quarries opened, and the great Cleveland ironstone district explored and opened up, all under his charge and direction. The latter event deserves special notice, for it was Mr. Marley and Mr. John Vaughan who made, what was felicitously termed, the "commercial" discovery of Cleveland ironstone. The actual discovery of ironstone in Cleveland had taken place years before, at least as early as 1811, and attempts had been made to bring some of it into use at various periods. Early in 1848 Messrs. Bolckow and Vaughan had collected and shipped to Middlesbrough several thousand tons found on the coast between Redcar and Skinningrove, and in the same year the main bed was discovered at Skinningrove and a shipment made from it in August. In September Messrs. Bolckow and Vaughan first requested Mr. Marley to examine it, and led his attention to the subject. They desired that efforts should be made to discover the same main bed or seam in the Eston and Upleatham hills, which were much nearer to Middlesbrough, and to which easy railway communication was possible. A seam was soon discovered, but it was only the one known as the top seam and of little value. This made Mr. Marley of opinion that the main seam should be found at Eston, and in March, 1849, he opened negotiations with landowners for right to search. All were not willing, and it was not until early in 1850 that, having made arrangements with one landowner, and still without having found the main seam, systematic search was prepared for. On the 8th of June, Mr. John Vaughan and Mr. Marley went to examine and decide upon the place for boring, and were so fortunate that day as to find the outcrop of the main seam, which rendered boring unnecessary. No time was lost in opening out the seam and laying tramways. Some of the ironstone was

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very soon in the furnace, by the end of the year 4,000 tons had been sent away, and in 1851 the output increased to 187,950 tons; the branch railway, 2 miles long, having been opened on the 6th of January of that year. The industry for which, on that occasion, a great future was predicted, has grown to be of world-wide fame.

The next important event during Mr. Marley's connection with the firm of Bolckow and Vaughan was the discovery at Middlesbrough of a bed of rock-salt in 1863. This occurred incidentally in the prosecution of borings for the supply of water. In 1868 Mr. Marley was engaged with Sir George Elliot in the compilation of information and statistics relating to the County of Durham for the Royal Commission on Coal. In 1870 he associated himself with the North Brancepeth Coal Company, Limited, as Chairman and Managing Director, an office which he held down to his last illness. He was much engaged in arbitrations respecting railway and mining undertakings, his services being retained as umpire and arbitrator as well as witness. He also had great experience in Parliamentary railway work. He had visited professionally nearly all the coal- and iron-fields of the United Kingdom, and some in Germany, Spain and Italy. In 1884–85 he was engaged in Cleveland to formulate the scheme for the rating of the Cleveland ironstone mines. From its formation, on the passing of the Mines Regulation Act of 1872, he was a member of the Mines Examination Board for South Durham, and was also on the chief committees of the Durham Coalowners Association.

Mr. Marley was a Member of the North of England Institute of Mining and Mechanical Engineers from its commencement in 1852. In 1857 he was elected a Member of Council, in 1872 a Vice-President, and in August, 1888, President, which office he held for two years to the great satisfaction of the members, devoting himself with characteristic energy to the interests of the Institute. To the Proceedings of the Institute he contributed several Papers, the chief being those on Cleveland ironstone. He took a leading part in the federation of the Mining Institutes, and was elected in 1889 first President of the Federated Institute of Mining Engineers.

He was a man of indomitable energy, and of great application, ability and resource, and was valued and respected by those with whom business brought him in contact. His manner was quiet but firm, and his bearing manly and courteous. He had many friends. His life was active and useful, and his loss is deeply felt.

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On account of ill health Mr. Marley had partially to retire from active business in May, 1890. He died on the 4th of April, 1891. He was elected a Member of the Institution on the 2nd of April, 1867.

LOFTUS PERKINS[1] was the third of a family of inventors. His grandfather, Jacob Perkins,[2] who was born in 1766, in New England, and died in London in 1849, was one of the most prolific of patentees. He took out—in the days of the old patent law—no less than nineteen patents, ranging over a great variety of subjects. Among these the most profitable was one for the method of transferring engraving by pressure, a device which, first intended for such purposes as the production of plates for printing bank-notes, was largely used for printing postage-stamps, and received its most important industrial application in the production of rolls for calico printing and similar purposes. He also devoted much attention to the utilization of steam at high pressures, a subject with which the most important inventions of his son and grandson were connected. The steam-gun was his most remarkable application of the principle, and this invention attracted a great deal of attention both in military circles and among the general public. As a young man Loftus Perkins had much to do with the working out of this invention, and to the end of his life was a great believer in its value, refusing to admit the force of the objections of practical artillerists. Angier March Perkins,[3] the son of Jacob, applied high-pressure steam, or rather, water heated under high pressure in a closed circuit, to warming and ventilating, and for the development of this system founded the firm, A. M. Perkins and Son. He also applied the same principle to heating bakers' ovens. This was perhaps the most commercially successful of any of the inventions of the family, though the larger share of the profits was absorbed by the firm of bakers who bought the original patent. Another important application of the same idea was to military field ovens, for which it is of great value.

Loftus Perkins was born in London in 1834, but, being of

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[1] In the preparation of this notice free use has been made of the Obituary which appeared in *The Engineer*, April, 1891.

[2] Minutes of Proceedings Inst. C.E., vol. xxv. p. 516.

[3] *Ibid.*, vol. lxvii. p. 417.

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American descent, always considered himself an American, and like his father and grandfather he passed some portion of his early life in the United States. After some years spent in his father's factory, he went to Germany, but soon returned to enter (in 1866) into partnership with his father, and from that date till the present year he continued the practice of his profession in London.

His most important work was the development of the high-pressure steam-engine. He is justly entitled to the credit of being a pioneer in the utilization of steam at the higher pressures now common in the modern steam-engine. In regard to this question he was in advance of his contemporaries, and many of his ideas, since generally admitted, were at first received with coldness, even with opposition and contempt. As far back as 1859 he had designed an engine which should work at 600 lbs. pressure, and he spent many years in perfecting that idea. The difficulty of lubrication he overcame by the use of metal packing-rings (made of an alloy of copper and tin), a device since largely and successfully adopted. Of the practical success of the high-pressure system in his hands there can be no question, for a certain number of the engines, both stationary and marine, are still successfully at work. Some have even been running regularly for twenty years. Its value was demonstrated by numerous and costly experiments, the most interesting of which was the dispatch of the 70-ton "Anthracite" to New York. The fact that this little yacht carried sufficient fuel to steam both ways across the Atlantic, was justly put forward as a practical and popular demonstration of the economy of the system, while careful tests, perhaps the most searching to which a steam-engine has ever yet been put, showed that, in the small engines tested, the amount of coal used did not amount to more than 1¼ lbs. per HP. per hour. The engine was, however, not a financial success, and this was a source of genuine grief to the inventor, who devoted to its development time and thought which might probably have been employed with better pecuniary results in other departments of his business. Commercial profit, however, was almost the last thought of Loftus Perkins, who had the true inventor's desire to realise in perfection the mechanical idea conceived, and was never content with a merely practical success, so long as he saw his way to a real or fancied improvement. Another invention—successful at all events up to the experimental stage—related to the application of steam-power to common-road traction. In this case perhaps the reasons for the invention not coming into actual use

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were legislative rather than mechanical, for he constructed a steam road-carriage which made numerous experimental journeys with success, running at high speeds, but under perfect control.

His minor inventions were numerous. Amongst the subjects to which they related may be mentioned, besides those specially referred to, marine propulsion, water-meters, heating and ventilating, and wheels for common-road carriages. An exhaustive test of iron gun-carriage wheels made under his system against the wooden wheels commonly employed led to a favourable report and a small order from Government, but from some unexplained cause the order was not repeated.

One of the earliest freezing-machines working with recovery of the volatile agent was that brought forward in 1834 by Jacob Perkins. At the time it had no great success, nor was there much demand for such an apparatus. Recent improvements in machines for the artificial reduction of temperature, and an increased demand for them in connection with the importation of meat, led Loftus Perkins to turn his attention to the subject. For himself the idea was an unfortunate one, for his work upon the apparatus which he devised, the anxiety caused by it, and the long hours which he devoted to the experiments necessary for its completion, tended to break down his health and bring on the illness which ended in his death. In principle the machine did not differ materially from other freezing-apparatus in which ammonia is employed, but the mechanical arrangements were, as in all Perkins' inventions, of great originality and of marked simplicity. There were no valves or other moving parts, and thus one difficulty in the construction of all ammonia machines was got over, since all joints could easily be made tight, and the risk of leakage was minimised. Unfortunately the apparatus was hardly completed before he was taken seriously ill, and was prevented from turning what was certainly an experimental success into what might have been a genuine commercial undertaking.

That a life still so full of promise should have been cut off at a comparatively early age was a source of sorrow to a large circle of friends, who saw with regret that his genius and original character never received either the appreciation they deserved, or the more solid rewards which might fairly have been expected for them. To those friends the sterling character of the man and his warm and generous heart had greatly endeared him, while his scrupulous honesty and the transparent sincerity of his mind compelled the admiration of all with whom he was brought in contact. With less enthusiasm and more thought for self he

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would doubtless have turned his really great abilities to better practical account, but he could not have left to all who knew him a more honoured memory or one to be preserved with more tender and affectionate regard.

Mr. Perkins died on the 27th of April, 1891. He was elected a Member of the Institution on the 31st of May, 1881.

WILLIAM COUPAR RENNIE was born at Kinross on the 3rd of December, 1843, and was educated at Dollar Institution, N.B. In 1862 and 1863, when serving with Messrs. Bell and Miller, of Glasgow, he attended the classes of the late Professor Rankine at Glasgow University, in which he gained some distinction. In 1863 he passed the necessary examination in London for an appointment in the Indian Public Works Department, and on the 24th of June of that year was appointed a Probationary Assistant Engineer. On arrival in India he was posted to the Berar Division, in the province of Hyderabad, Deccan, where he remained till the 23rd of February, 1865, when he resigned the Government service. For the next two years he was employed by Messrs. Lee, Watson and Ayton, contractors, as one of their agents on the construction of the Nagpur branch of the Great Indian Peninsula Railway.

In April, 1867, Mr. Rennie was re-appointed to the Public Works Department of the Government of India, and was again posted to Berar. In Berar, which at that time was a new and backward province, and which, owing to its capacity for growing cotton, had come into prominence by the breaking out of the American Civil War, he did much good work in laying out and constructing roads, and in the erection of the many new public offices and buildings which were required for the civil administration of the district.

In June, 1868, Mr. Rennie was prostrated with sickness, and had to take leave to Europe. On his return to India in November, 1869, he was posted to the Nizam's State Railway, on the survey and construction of which he did much good work. For first-class execution of work he received the acknowledgments of the Governor-General in Council. In December, 1873, he was trans-

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ferred to the Scindiah State Railway, where he remained as an Executive Engineer of one of the divisions during the survey and construction of the line. In May, 1879, Mr. Rennie was sent to Bombay as Superintendent of Works, under Mr. Alexander Izat, to lay out and construct the Bhavnagar-Gondal Railway, 193 miles in length. The funds for this line were provided by the native states of Bhavnagar and Gondal, and, besides opening out the peninsula of Kathiawar, it was intended to give employment to the people who had suffered during the famine which then existed. The survey was begun in the middle of the hot weather in May, 1879, and by the end of May, 1880, 103 miles of the line had been laid and were in running order, and the remainder was ready for the rails. During the hot weather and monsoon of 1879 the staff had to live in tents, and had a trying time, most of them suffering from a malignant form of fever. It was in a great measure due to Mr. Rennie's good management that the works were laid out and pushed forward so rapidly. In November, 1880, he took furlough to Europe.

On his return to India in December, 1882, Mr. Rennie was placed in charge of the survey of the proposed line from Dacca to Chittagong. For the energetic way in which it was carried out he received the thanks of the Lieutenant Governor of Bengal. On the 4th of June, 1883, he was appointed Superintendent of Works on the Northern Bengal State Railway. The climate of Bengal, however, did not suit him, and he was, on application, transferred to the Jhansi-Manickpur State Railway, which now forms part of the Indian Midland Railway.

On the formation of the Indian Midland Railway Company, Mr. Rennie's services were placed at the disposal of that company, with which he remained, in the capacity of Deputy-Agent, till May, 1887, when he again took furlough. On his leaving for Europe and breaking his connection with the Company, Mr. A. C. Cregeen, the Agent and Chief Engineer of the Company, wrote as follows: "I take this opportunity of placing on record my high appreciation of the services rendered by Mr. Rennie since the date of his connection with this railway. It is mainly due to his wide professional experience and his business habits that, in the carrying out of the works connected with this railway, a considerable reduction of rates, which were prevalent in the Jhansi district at the time when the company commenced operations, has been obtained, and which will result in large savings to the company in the cost of works at Jhansi itself, and on the Jhansi-Bhopal section of this railway system."

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Mr. Rennie retired from the service of the Government of India in 1890, and his friends thought that, with his robust constitution, he had before him many years of life. His heart, however, was affected, and he died at Dollar on the 5th of April, 1891, after a short and painful illness.

Mr. Rennie was of a sanguine and energetic temperament, and had great capacity for organizing and carrying out works and for managing men. His shrewd common sense and genial disposition endeared him to many people and made him a large circle of friends.

He was elected a Member of the Institution on the 3rd of May, 1881.

EDWARD SLAUGHTER was born in London, on the 1st of December, 1814, and was educated partly at the school of Dr. Nicholas at Ealing, and partly in Paris. He served a pupilage of five years to Mr. John Seaward of the Canal Ironworks, Limehouse. After some two years of travel (1836 and 1837), he joined Mr. I. K. Brunel in 1837 as Assistant Engineer, and took part in the construction of the London end of the Great Western Railway, especially in laying the permanent way over a large portion of the line, building stations, and general work. Mr. Slaughter's ability was highly esteemed by Mr. Brunel, who subsequently gave him a post at the Bristol end of the line. Upon the opening of the line to Hay Lane, near Swindon, in December, 1839, he accepted the offer of Messrs. Henry Stothert and Co. of Bristol, who had recently started engineering works, to join their firm as managing partner, specially with a view to the manufacture of locomotive engines. The partnership was formed early in 1840 under the style of Stothert, Slaughter, and Co., which was changed in 1856, when Mr. Henry Gruning was admitted, to that of Slaughter, Gruning, and Co. The concern developed into a large business under the personal management of Mr. Slaughter, and was carried on with great success for many years. In the year 1866 the business was converted into the Avonside Engine Company, Limited. Mr. Slaughter retained the engineering and general management, taking the title of Managing Director, which post he held until 1873, when failing health induced him to abandon active work. During this period he was much abroad,

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where he devoted special attention to the peculiar conditions of foreign railways, and supplied nearly one thousand locomotives, besides some marine and stationary engines and iron steamships. Mr. Slaughter was greatly interested in the improvement of the steamboat service between Bristol and Newport. He designed and built two screw-steamers fitted with engines of the locomotive type, working direct on to the screw-shaft. These boats, the "Avon" and "Severn," were very successful and did good service in competition with the old paddle-boats. The passage which formerly occupied about three hours (and sometimes eight by reason of missing the tides in the rivers) was reduced to two hours. These steamers became the property of an independent company, and continue at work at the present time. As many of the locomotives were furnished to foreign railways, in which for the most part steep gradients and sharp curves were employed, he took a prominent part in the introduction of the various articulated or bogie systems. A visit to the United States confirmed and developed the views and practice he had always advocated on this head. Continually increasing deafness, a weak voice, and feeble health, caused him to withdraw with much regret from active participation in engineering work, but he continued to take a warm interest in the published Proceedings of the Institution, of which he was elected a Member on the 6th of December, 1858. He died on the 13th of May, 1891.

Mr. Slaughter was a man of considerable character and parts, and formed an important factor in Bristol life. His reputation as a mechanical engineer, especially in connection with locomotive construction, was of the highest class. He was an excellent judge of work, and was ruled by the strictest sense of honour in all engagements he undertook.

BENJAMIN WALKER was born at Armley, near Leeds, on the 20th of April, 1821. At the age of fourteen he was bound apprentice to Messrs. Newton and Taylor, engineers, of Leeds, for seven years, and at twenty became foreman of a large shop. He received the larger portion of his book-learning at a night-school in Armley, walking direct from the workshop in Water Lane to the school. He worked very hard at the night-school, and when his apprenticeship expired was a good mathematician, and had

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acquired a considerable store of scientific knowledge. He was one of the first members of a literary society which was formed in Armley about the year 1838. Before he was twenty he was well known for his skill as a mechanic, and he used to tell with pride how his master would send him to various mills in Leeds to put right machines when other men twice his age had failed to do so. On one occasion he was thus admonished: "Na, Ben, this machine won't work, and thou must go and put it right; and if thou hasn't got a tall hat thou had better borrow one, for thou art as good as a man, and we shall charge a man's wage for tha." He went to the works in question, and the proprietor, seeing how young he looked, received him somewhat contemptuously, but, as the machine was soon put in order, finished by being delighted with him. Soon after he was twenty-four years of age Mr. Walker went to Belfast to be manager of the works of Messrs. Combe and Dunfield (now Combe, Barbour, and Combe, Limited). He left these works in full operation in the latter part of 1847, when three hundred hands were employed, and went to Leeds to work as an ordinary engine-fitter, so that, as he said in after years, he might devote his mind fully to the acquisition of mathematical and mechanical science. He had found that the direction of large works prevented his gaining the knowledge he felt he so greatly needed. He left Belfast at a great sacrifice in a pecuniary sense. A few years later he accepted the position of foreman at Messrs. Kitson, Hewitson, and Thompson's works, where he afterwards became manager. In 1851 he invented several important appliances for making forgings at reduced cost, and in 1860 he introduced, in conjunction with the late Mr. William Hewitson, an ingenious self-acting motion for double-acting steam-hammers, substituting for the noisy and destructive tappet-motion then in use one more like the gliding motion of the eccentric of the steam-engine. A large number of steam-hammers have been made on this system, for which Mr. Walker received a medal at the Paris Exhibition of 1867. He also invented a wrought-iron wheel for traction-engines, in place of the old wooden wheel with metal tires, and devised the frame slotting-machine now in universal use. In the year 1862 he commenced business in Hunslet, Leeds, at the Goodman Street Works, now among the largest in the world for the manufacture of hydraulic machinery and for machinery used in the making of iron and steel. As early as 1863 he proposed to make for a Sheffield firm a forging-press to be used instead of a steam-hammer; the proposition was not accepted at that time, and it is only during the past few years

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when the masses of steel to be dealt with have gradually increased that the superiority of the press over the hammer, not only for working the steel into form, but for pressing it to the core and making it denser, tougher, and stronger, has become recognized. Mr. Walker's firm has made forging-presses for all the European governments and for many of the largest engineering works of this and other countries. He made the first hydraulic-press for bending armour-plates, and supplied machines of this type to the principal shipyards in Europe. Mr. Walker introduced improvements in the machinery for the Bessemer process, with which he was very early associated, and on the introduction of the basic process he made the first converters and hydraulic machinery. He also achieved repute in the rolling of weldless tires, and in reversing apparatus for rolling-mills. He was one of the first to propose making Bessemer blowing-engines compound, with the result of saving 30 per cent. of the fuel, and the earliest compound reversing rolling-mill engines were made by his firm. He was the first to introduce the separate condensation-engine for taking the exhaust steam of one or more engines. He also introduced the three-cylinder blowing-engine for cupolas and smiths' fires, which has to a great extent, owing to its economy and efficiency, replaced fans and other blowers. He carried out many improvements in hydraulic cranes, the most notable being the double-ram centre or ingot-crane for economizing water. The original machines of this type were plain centre-ram cranes, the water either acting on the bottom of the ram, or the said ram was made of two different diameters, so that the water pressing on the concentric area raised the jib and the load. This arrangement was wasteful in pressure-water, as it necessitated power to lift not only the load but also the dead weight of the jib. Mr. Walker employed the centre-ram as a guide and to take the strain only, and introduced two side rams, one in constant communication with the accumulator, nearly balancing the dead weight, and the other under the control of the workman by means of a valve. Cranes on Mr. Walker's double-ram system have been supplied to nearly all the large steel works and arsenals.

His latest achievement was the combined vertical and horizontal press for forging steel slabs and ingots. Increase in the pressure of steam and in the sizes and speeds of ships brought about the use of larger and thicker plates, necessitating much larger ingots and a higher quality of steel. Mr. Walker early recognized the absolute necessity of working the plate ingot on the edge as well as on the flat, and the horizontal and vertical forging-press was the outcome

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of this necessity. By his system plate ingots of any size can be squeezed horizontally and vertically, the ends cut off, and the slab cut into pieces with practically no hand labour, the quality of steel being improved and the waste greatly lessened.

Mr. Walker was a magistrate of the borough of Leeds, and a member of the Liberal Unionist party. He was elected a Member of the Institution on the 2nd of December, 1873, and frequently attended the meetings. In 1880 he contributed a Paper to the Institution, entitled "Machinery for Steel-Making by the Bessemer and Siemens Processes,"[1] for which he was awarded a Telford Medal. In the year 1885 he was a Member of the Jury of the International Inventions Exhibition, receiving a certificate and medal for services rendered. He was also a Member of Council of the Institution of Mechanical Engineers, and of the Iron and Steel Institute. He died on the 4th of April, 1891, after a very brief illness.

Mr. Walker was a thoroughly practical engineer, in whom the inventive faculty was largely developed, and who exhibited great determination and force of character. To these qualities were added a genial nature and an honourable regard for his engagements which won him universal respect.

ARTHUR TURNOUR ATCHISON, the youngest son, by his second wife, of Lieut.-Colonel H. A. Atchison, was born at Bath in 1848. He was at school at Brighton, and in 1866 he went up to Christ's College, Cambridge, with a minor scholarship, which he afterwards exchanged for one on the foundation. He took his degree in the second class of the Mathematical Tripos of 1870. During his residence at Cambridge he acquired considerable distinction as an oarsman and a gymnast. He rowed stroke in his College boat in 1871. In 1869 he rowed in the "trial eights" from which the University crew is selected, and only just missed a place in the Cambridge boat. He also won prizes for sculling and in athletic sports. In the gymnasium he made the friendship of Professor W. K. Clifford, a friendship which

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 2.

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continued until Clifford's death. In 1879 an adventure of theirs was referred to in his introduction to Clifford's collected works, by Frederick Pollock, to whom "a friend" (Atchison) wrote: "I am appalled now to think that he (Clifford) climbed up and sat on the cross-bars of the weather-cock on a church tower, and, when by way of doing something worse, I went up and hung by my toes to the bars, he did the same."

On leaving Cambridge, he was a pupil for one year to Messrs. James Simpson and Co., Grosvenor Road, Pimlico. He was afterwards articled to Mr. James Abernethy, Past-President Inst. C.E. In November, 1872, he was sent to Newport, Mon., to assist in superintending the construction of the Alexandra Docks. Then he was employed in making surveys, &c., for the purpose of easing the sharp curves of, and generally improving, the Monmouthshire railway, which had recently been purchased by the Great Western Railway Company.

After passing some little time in the office of Mr. Bailey Denton, he, in 1877, started in London on his own account, in offices in Great George Street. Thence he moved, in 1883, to Parliament Street. His chief work in London was connected with the preparation of reports and plans for parliamentary deposit in connection with railways, tramways, schemes for water supply, &c., and he was attaining an increasing practice when his career was interrupted by the illness which eventually caused his death. He was associated with Mr. Hart in the construction of the Shanghai Waterworks, and assisted in the preparation of a scheme for the water supply of St. Vincent. He also visited Florida (in 1881) to report on some proposed works, and Ceylon (in 1875) in connection with coffee plantations belonging to his father, who had served in that island for the greater part of his military career. Amongst other matters in which he was engaged may be mentioned the Hull and Barnsley railway, and the proposed new line to Brighton.

Arthur Atchison was for some time a contributor to *Nature* of articles on mechanical subjects. He revised and edited the second edition of the catalogue of the Loan Exhibition (1876) of Scientific Apparatus, the first edition of which was hurriedly issued and very incomplete. He was also associated with the Smoke Abatement Exhibition (1882), and with the Health and Inventions Exhibitions (1884 and 1885). He took an active part in the Jury work of both the latter, and in the organization of the conferences held in connection with the Health Exhibition.

In 1872 he became, at the instance of his friend Clifford, a Member of the British Association, and in 1874, at the Belfast Meeting, he

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undertook the duties of Secretary of Section G (Mechanics). He filled the same office again in 1877, and from that time continuously until 1886, accompanying his Section to Montreal in 1884. In 1886 he was elected Secretary to the Association in succession to Professor Bonney. This position he held for the Meetings at Birmingham (1886), Manchester (1887), Bath (1888), and Newcastle (1889); though even in 1887 his health was failing, and in 1889 he was really much too ill to have persevered in the work. To many members of the Association he will, however, be best remembered, not for his official connection with it, but as the witty and popular secretary of the "Red Lion" dining club—a club which probably owes its continued existence to the interest taken in it by Clifford and Atchison, and a few of the special friends who were always happy to be associated with the latter in anything he undertook. The humorous speeches which year after year never failed at the annual dinner, will long live in the memory of the "Red Lions" of the British Association of that date. Full of quaint conceits, brimming over with pure fun, lighted up with flashes of the readiest wit, and wholly free from malice or even the slightest touch of sarcasm, they never contained a word which could annoy or hurt anyone.

It was in 1885 that signs of the illness (pulmonary consumption), which eventually proved fatal, first showed themselves. In the autumn of that year he was ordered abroad, and a voyage to the Cape causing no improvement, he stayed to the end of the winter (1886) at Madeira. In the autumn of 1889 he went to Mentone, and there he spent the winters of that and the following year. He died at that town on the 21st of April, 1891.

Endowed with a singular power of attracting and attaching to himself all with whom he was associated, Atchison had made a large circle of personal friends, all of whom appreciated and admired his quick and ever-ready humour. To a smaller number he was endeared by his sweet and affectionate nature, while the few who saw the cheery courage which never failed through the course of a long and painful illness, or even when the inevitable end came, feel that for them at least a notable amount of the brightness of life disappeared with the passing away of that genial spirit.

Mr. Atchison was admitted a Student of the Institution on the 29th of November, 1870; was elected an Associate on the 13th of January, 1874, and was transferred to the class of Associate Member, on its creation, on the 2nd of December, 1878.

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EDMUND LINCOLN HARPER was born on the 2nd of August, 1850. When sixteen years old, he entered the office of Messrs. Kelk, Waring Brothers, and Lucas, joint contractors for the Metropolitan District Railway, and, with the exception of an interval of five months, was employed by them in the drawing-office and upon works, until the 31st of August, 1871. On the completion and opening of those works, and with an excellent testimonial from his late employers, he was engaged by Messrs. Greenfield and Company, as draughtsman and assistant on the Alexandria Harbour Works, for which they were the contractors. Mr. Harper remained in Egypt for seven years, during which time he acquired much valuable practical acquaintance with the management of Eastern workmen, as well as thoroughly mastering Arabic and the *lingua franca* of the Levant. Returning home in the autumn of 1877, he was for a short time employed in Parliamentary surveying; but in the spring of the following year was engaged by Mr. Edward Easton, by whom he was entrusted with various important prospective surveys, computations of watersheds, reporting upon water-works, and the like. In March, 1879, he was again in Egypt as assistant engineer for Mr. Easton, on works of water-supply and irrigation. Two years later he became Chief Engineer of a French company, the "Société générale de Travaux en Egypte," having charge of their irrigation-works in the delta of the Nile; but the outbreak of war obliged him to resign his appointment in June, 1882. Mr. Harper returned to England, but in the following September he was engaged by the British Government in connection with the campaign against Arabi, and was on the point of sailing for Egypt when the decisive battle of Tel-el-Kebir rendered his services unnecessary. The appointment was therefore cancelled, Mr. Harper receiving compensation. He next acted as District Engineer on the Rio Grande do Sul railway in Brazil, and on the Suakim-Berber railway in Egypt, and afterwards commenced practice on his own account in London. Mr. Harper subsequently proceeded to South America as Resident Engineer on the South Western of Venezuela Railway. He died of yellow fever at Aroa, Venezuela, on the 8th of June, 1891.

Mr. Harper was elected an Associate Member of the Institution on the 1st of December, 1885.

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JOHN JACKSON, who was born on the 3rd February, 1834, at Brewood, Staffordshire, was the second son of the late Thomas Jackson, of Eltham Park, Kent, a well-known contractor for canals, breakwaters, and railways. After being educated at King's College, London, he served for some years under Messrs. Branson and Gwyther, contractors and builders, of Birmingham. In 1852 John Jackson went to Alderney, where his father, in conjunction with Mr. A. W. Bean, of Danson Park, Welling, Kent, had taken a large contract for building a breakwater and fortifications. He superintended the building of the latter until 1857, when he took charge of both works until 1866. The engineering difficulties involved in the construction of the breakwater revealed themselves in all their magnitude as the work progressed: a site more difficult for such an erection could hardly be conceived. The breakwater was rather under a mile in length, the superstructure was 45 feet wide and 50 feet from the foundation to the top, whilst the rubble mound on which it was built extended to a depth of 130 feet at low water spring tides.[1] It was exposed to the full force of the Atlantic waves, which, often lashed by westerly gales into tremendous fury, made clean breaches through the masonry superstructure, in one case to the extent of some 180 feet in length, costing £13,500 to repair. Altogether there were twenty breaches during the twenty-five years of construction and maintenance, up to 1872. The labour, difficulty and trouble of erection were far greater than the engineers or contractors could ever have contemplated. The first Armstrong gun mounted in this country was placed in the Alderney fortifications. During Mr. Jackson's first year in charge, the Queen, accompanied by the late Prince Consort, visited the island during a yachting tour. Owing to the military authorities being without instructions from headquarters, they could take no part in the preparation for Her Majesty's landing, which fell upon the contractors. As the resources of the little island were very limited, they had to transform a locomotive tender into a carriage, which, drawn by two powerful black horses, enabled the Queen to inspect the works and forts.

In 1866 Mr. Jackson left the island to take up several railway contracts in partnership with his brother Thomas. They constructed the Market Weighton and Beverley, Stamford and Essendine, and Spalding and March Lines. In the construction of the latter they encountered serious difficulties, owing to the boggy nature of the soil,

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 60.

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and the embankment between Cowbet and Guyhire suddenly subsided about 6 feet, for the reconstruction of which some millions of faggots were used. In 1872, in conjunction with the late Mr. George Wythes of Bickley Park, Kent, Mr. Jackson constructed the Rio Quarto Railway in the Argentine Republic. In 1874, Messrs. Wythes and Jackson, also surveyed and constructed the Natal Government Railways from Durban to Maritzburg, and of the North and South lines from Durban to Isipingo and Verulam. In 1887 Mr. Jackson undertook the construction of the Argentine Northern Central Railway extensions, which were nearly completed when he died. These extensions were over 400 miles in length.

Mr. Jackson was a great lover and supporter of athletic sports, and in all his different undertakings each section of the works had its cricket and other clubs. In 1887 and 1888, when he went to Buenos Ayres to inspect the different lines of railways he was constructing there, he took with him a well-known Sussex cricketer, with a view to give zest to the game in that country. He was an old supporter of the Sussex team, and hired a field and built a Pavilion at Willingdon for the local players.

In politics Mr. Jackson was a strong Conservative, and was returned as one of the Ward representatives when Eastbourne was first formed into a Corporation. In 1889 he was persuaded to stand for the new County Council for Sussex, and was returned at the head of the poll. Hospitality and kindness of heart were the prominent features of his character. He was always ready to lend a helping hand to those who required it, and in an unostentatious way he disbursed large sums in charity.

Mr. Jackson was elected an Associate of the Institution on the 4th of April, 1871. He died on the 14th February, 1891.

*** The following deaths, in addition to some of those included in the foregoing notices, have been made known since the 5th of June, 1891 :—

Members.

BLAIR, WILLIAM NEWSHAM; *born* 1841; *died* 4 May, 1891. (*Disease of the kidneys.*)

DU PORT, WILLIAM JANVRIN; *born* 22 March, 1834; *died* 20 June, 1891.

MACKENZIE, JOHN; *born* 2 January, 1827; *died* 24 May, 1891. (*Pneumonia, following influenza.*)

PENNY, ALFRED; *born* 7 March, 1841; *died* 7 July, 1891. (*Blood poisoning.*)

SHELLEY, CHARLES PERCY BYSSHE; *born* 1827; *died* 16 June, 1891.

WYNNE, THOMAS; *born* 7 February, 1807; *died* 4 June, 1891. (*Effects of a carriage accident.*)

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Associate Member.

RILEY, JOHN HENRY; *born* 26 February, 1856; *died* June, 1891.

Associate.

DYSON, GEORGE; *born* 11 November, 1817; *died* 10 May, 1891.

Information respecting the life and works of any of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 14 *July*, 1891.

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SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

A Cofferdam or Caisson without Timber or Iron in its Construction. By R. L. HARRIS, M. Inst. C.E.

(Advance proof, Transactions of American Society of Civil Engineers, March 1891.)

The New York and Northern Railway Company having determined, during the winter of 1888–9, to replace a single-track iron bridge, crossing Croton Lake, by a heavier structure, more in accordance with modern standards, the Author was entrusted with the direction of the mason's work. The substructure consisted of masonry resting upon cribs, 47 feet by 35 feet, each crib having nine compartments filled with stone; the depth of water at the southerly crib was about 18 feet, and at the northerly crib about 28 feet. The cribs and masonry bases of piers were built about the year 1869. On examination of the existing masonry, though it was found to have a good external face, the interior was so defective that no reliance could be placed upon it to support the new structure. It therefore became necessary to strengthen the cribs and to obtain a solid foundation upon which to work. A mass of rip-rap, having a berme of 7 to 10 feet at the level of the top of the crib, and a slope of $1\frac{1}{4}$ to 1, was placed round each crib. The tops of the cribs were about 5 feet under water, just sufficient to require diving appliances, or a cofferdam, or caisson of some kind, to permit of the removal of the rotten work within the ashlar-facing of the piers. As much of the defective rubble-work as was possible was got out by hand, chains, and grapples, but the water was too muddy to permit of careful work at the sides, ends, or corners. The bottom of the lake was irregular, and contained many boulders; the old rip-rap, though scant, was spread out, and it was found requisite to place the new rip-rap before interfering with the bases. In order to get a tight bottom on which to work, many expedients were proposed, such as forcing sheet-piling through the rip-rap, covering its entire surface with tarpaulin, &c., but these were, in turn, rejected as impracticable. Ultimately the Author decided to attempt to use the materials that were in place, and to make a caisson therein without disturbance, by cementing together a portion of the loose, irregular stone-filling of the crib to form the floor of the caisson, and on this bottom to build in cement up to the surface of the water; forming by this means a workin-

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chamber that might be pumped out. The track upon the bridge was 75 feet above the crib, and grout could be mixed on the track and delivered by a hopper-pipe and nozzle into holes driven into the loose rubble filling of the crib. These holes were pushed and worked among the stones until a depth of several feet below the top of the crib had been reached, and they were kept open as long as necessary by crowbars, pipes, poles, &c. It was soon found advisable to pump in the grout at the water-level instead of from the track, and for this purpose a No. 2 Douglas hand force-pump was used, having a long nozzle of 1½ inch pipe, connected with the discharge-pipe. This nozzle was inserted down to the bottom of the hole, and the water was pumped through for a few minutes, then the suction hose was suddenly transferred to a reservoir of grout, composed of equal parts of Alsen Portland cement and fine sharp sand, mixed immediately before use. Two or three barrels only at a time of the grout were forced slowly through, and then the nozzle was withdrawn—the hole being kept open—and the work recommenced at another hole, grout being seldom forced into the same hole twice in one day. The idea was that the cement in the quiet water would accrete on the surfaces of the irregular stonework, at and below the level of injection, and that by slight consecutive injections, at proper intervals of time, the voids between the stones would be filled up. After these operations had been repeated for many days, and when attempts had been made with a 6-inch centrifugal steam-pump to empty the caisson on several occasions unsuccessfully, the Author found, on a certain Monday morning, after a quiet settling of thirty-six hours, that the steam-pump lowered the water a few inches. Being thus assured of success, he continued the introduction of the grout for a few days longer, and at the next trial he pumped the space dry in a few minutes.

It was then possible to proceed with the excavation, and the inflow of water was so slight that at times a single man at the hand-pump kept the chamber free. A very rich concrete was then spread over the bottom and brought up to the surface in solidly-rammed layers, each of 9 inches in thickness. It was found, during the excavations, that, at 6 feet away from the nearest nozzle-hole, some of the stone had been coated with half an inch of cement. No loss of cement through the rip-rap could be traced during the execution of the work; and such was the success in the case of the piers in 18 feet depth of water, that the process was repeated with equally good results for the other pier in 28 feet of water. All this time trains were running at low speed over the spans still *in situ*. Details are given of the new piers and bridges. The Author states that this mode of proceeding may be used with equal advantage for gravel, sand, and even quicksands, and for many sub-aqueous structures.

G. R. R.

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Repairing the Foundations of a Bridge-Pier.

By CONWAY B. HUNT.

(Proceedings of the Engineers' Club of Philadelphia, 1890, p. 232.)

In the summer of 1889 a great deal of damage was caused in Washington City, by a flood in the Potomac river, which rose to a height unequalled in any previous records; and at the Aqueduct bridge, where the flood rose 20 feet above mean low-water, the current was observed to be especially violent at the first pier from the south end, which is known as Pier No. 1.

The river bottom consists generally of rock at a depth of 25 to 35 feet below low-water, covered by a deposit of mud of varying thickness. When the bridge was built, in 1835, the thickness of the mud stratum was 18 feet, but in 1887 this had been reduced to about 5 feet, and after the flood of 1889 it was found to be wholly scoured away.

The watchman, while making an examination of the roller-ends of the iron trusses on July 4th, noted a condition of affairs which he described by saying that the south span from Pier No. 1 had contracted about 2 inches, while the north span had expanded by the same amount.

This matter having been looked into, it was found that the top of Pier No. 1 had moved $2\frac{3}{4}$ inches northwards, carrying with it the fixed bearing and trusses of the second span. The top of the pier was $\frac{3}{4}$ inch out of level, dipping towards the north; and as there was no sign of failure in the masonry of the pier it was concluded that the flood had probably caused a settlement in the foundations. Accordingly a submarine examination was made, and it revealed the existence of a scoured cavity under the north edge of the foundation, 4 feet high at the lip of the masonry, and running back 6 feet under the pier. The cavity extended the full length of the pier, and its bottom was found to be solid rock for one-third of the length, and sandy silt for the remainder; but going away from the pier the limit of the sand-pocket was found at about 15 feet from the pier, where the rock appeared again.

On consulting the reports of Major Turnbull, under whose direction the bridge was built in 1836, this depression in the rock surface was found to be therein described. It appeared from these records that the foundations had been excavated within a cofferdam constructed after the model of those used by Perronet at the bridges of Neuilly and Orleans, but the work had been attended with serious difficulties owing to the great depth and the violent inrush of water and sand. After many unsuccessful attempts, the rock had been laid bare over the greater part of the area, leaving however the above-mentioned depression, which was said to be filled with compact gravel with a rock bottom about 2 feet beneath the levelled surface; and as the bottom of this hole was beyond the reach of the pumps, while the removal of the

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gravel would probably induce further difficulties, it was decided to carry up the masonry upon the foundation thus prepared. The lowest course is laid at a depth of 35 feet below low-water, and covers an area 66 feet by 22 feet. The pier has a total height of 65 feet, and under the coping its dimensions are 42 feet by 7½ feet.

The facts recorded in 1836 appeared to afford a sufficient explanation of what had now happened; the flood had first removed all the protecting material from around the base of the pier, and had then scoured under the edge of the masonry, gradually emptying the pocket and producing the settlement of the structure. The movement of the top towards the north, which amounted to nearly 3 inches on July 6th, continued to increase daily until it reached 3½ inches on July 11th. Its further continuance threatened the stability of the structure, and it was determined at once to restore the supporting material by means of concrete lowered in bags and stowed under the pier by divers. The work was commenced on the 13th and finished on the 26th of July.

The method employed was to fill the cavity as completely as possible with bags of concrete, and to construct a bulk-head of bags at the mouth of the cavity to form the outside face of the concrete, its base being well bonded and toed into the irregular rock bottom of the river. After this had been done, loose concrete was lowered in tubs, which were tripped, and the material was pushed with hoes and special tools into all the remaining portions of the cavity until it was completely filled with a solid mass of concrete. What remained of the original sand-pocket beneath the pier was left undisturbed, as the risk attending its removal was considered too great. The whole of it was therefore enclosed bodily within the mass of concrete, which extended beyond its limits and confined it on all sides.

The concrete was composed of 1 part of quick-setting Portland cement, 1 part of sand, and 2 parts of fine broken stone. The bags were filled from two-thirds to three-quarters full and the mouth sewed up with twine. Their loose and flexible condition then permitted their being stowed in any desired position, and the accommodation of their shape to every surrounding irregularity assured a firm bond when the contained material should become set. In the execution of the work three hundred and fifty-one barrels of cement were used, two hundred and twenty-one being used in the bags, and one hundred and thirty in the loose concrete. The bags would hold about 2 bushels each, and of these one thousand four hundred and fifty were placed in position. After the work had been taken in hand the subsequent settlement was very slight, and ceased on the 17th July, when the movement had reached 4 inches. No further settlement has since occurred.

T. C. F.

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The Results of Deflection-tests on Loaded Railway Bridges.

By E. PASCHEN.

(Annalen fuer Gewerbe und Bauwesen, vol. xxviii., 1891, p. 115.)

It is pointed out that in the case of the earlier tests by means of a lath, it was only possible to obtain a single straight line, showing the greatest amount of deflection under a given load, and no indication was afforded of the nature of the movement before and after the maximum deflection was attained. The Author calls attention to the valuable information yielded by the character of the curve traced on a strip of paper wound on a cylinder, which is moved by clockwork, on the principle of Askenasy. This cylinder is attached to a support independent of the bridge or structure to be tested, and a pointer secured firmly to the bridge traces a curve, or a series of curves, showing the movement which takes place under the influence of a load. The arrangement of the apparatus is explained by reference to a diagram, and a series of curves obtained from various descriptions of lattice- and solid girder-bridges are given and analyzed by the Author. In some cases the effect of the rolling load is, in the first case, to raise and then to deflect a given point in the structure. The difference in the curves traced when the movement is rapid and when it is slow is also pointed out, and certain deformations in structures, where the load is on the bottom flanges without struts or cross-ties at the tops of the girders, are explained by diagrams.

The opportunity was taken to obtain a series of tracings from an old wooden bridge over the Elbe, now only used as a road-bridge, and the peculiarities in the curves obtained are investigated by the Author, who states in conclusion that the careful examination of the curves traced by the means he indicates, would seem to furnish many useful points to those interested in bridge-construction.

G. R. R.

The Pollution and Self-Purification of Streams.

By F. P. STEARNS.

(Report of the State Board of Health of Massachusetts, U.S., p. 783.)

It is pointed out that there are numerous cases in which sewage is discharged into a stream without being productive of such an amount of pollution as to be seriously objectionable, when the water is not used for the purpose of domestic supply; while on the other hand many streams receive so much sewage as to be rendered positively foul and offensive. The border line between these two conditions is necessarily somewhat indefinite, and owing

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to the lack of information as to the effect of a given quantity of sewage upon a given quantity of water, this dividing line cannot be clearly laid down. The Author states that the investigation of the rivers in Massachusetts furnishes some information which throws a light upon the subject. In order to prevent discrepancies due to the varying extent to which sewage is diluted, the basis of calculation adopted is that of population in relation to the quantity of water flowing in the stream. This latter volume is commonly expressed in cubic feet per second, and in order to avoid the use of too small quantities, one thousand is made the unit of population. It is shown that two methods are available for the determination of the quantity of water which will so far dilute the sewage of one thousand persons as to render the same unobjectionable; first, by actual experience in the discharge of sewage into streams where the population connected with the sewers and the volume of water flowing in the stream are known, and second, by chemical analysis of water polluted to the utmost extent possible, and subsequent calculation of the relative population to volume of water which will produce corresponding results.

The second method of computation is in the first instance examined, and the Author deals with the data available for such a calculation in the report of the Royal Commission on Metropolitan Sewage Discharge. From the analyses of Mr. Dibden, one hundred and eighty-one in number, it is estimated that, to 333 pounds of sewage water per head, the dry weather flow, the following constituents were daily contributed by each person:—

	lb.
Free ammonia	0·015
Albumenoid ammonia	0·0018
Dissolved solids	0·191
Chlorine	0·045

From these and from corresponding figures obtained for the sewage of Worcester and Lawrence, an average is prepared, and it is assumed that each normal inhabitant contributes the following constituents daily to change water into sewage:—

	lb.
Free ammonia	0·015
Albumenoid ammonia	0·003
Dissolved solids	0·218
Chlorine	0·042

From these figures the composition of sewage of various degrees of dilution is computed, and a Table is prepared showing the amounts of the above substances added to streams by domestic sewage for various ratios of population to quantities of water flowing, expressed in cubic feet per second per one thousand people, from 0·5 cubic foot up to 100 cubic feet. In order to make practical use of the Table, it is necessary to compare the calculated analyses with the analyses of polluted streams. The free ammonia serves as the best index, as this substance is found only in extremely small quantities in unpolluted water. The

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Author proceeds to examine various sewage-polluted water-courses, rendered foul by the populations of townships on their banks. In these the amount of free ammonia varies from 0·02 to 0·216 parts per 100,000, while he states that several instances could be enumerated where streams containing from 0·01 to 0·03 part of free ammonia per 100,000 parts, were found to be free from offensive odours. To keep within safe limits it is assumed that volumes of from 2·5 to 7·0 cubic feet of water per second per one thousand persons, and containing free ammonia, from 0·1116 to 0·0399 part per 100,000 should be regarded as doubtful. With smaller volumes of water the pollution is so great as to be inadmissible; with larger volumes the dilution is such, from the standpoint of offensiveness, as to be clearly admissible. If certain manufacturing uses are to have weight, it might be expedient to insist upon even greater dilution than this. From the standpoint of domestic supply it cannot, so far as is at present known, be pronounced that any degree of dilution will render sewage-polluted water entirely safe.

Upon the question of self-purification, a most important one, when the water has to be used subsequently for drinking purposes, the Author insists upon the need of bacteriological as well as chemical investigation. From the analyses of the Blackstone River, at three different points, the Author concludes that between the townships of Worcester and Uxbridge, a flow of 16 miles, the quantity of albumenoid ammonia was reduced by rather more than one half, viz., from 826 to 306 lbs. The proportions present of other constituents are discussed, and the state of things prevalent in other polluted streams is examined. The Author remarks that while the rapid decrease in the amount of free ammonia below the cities mentioned points to the self-purifying power of rivers, no indication is afforded whether there is a similar decrease in the number of disease-germs. Moreover, it cannot be ascertained that there is any corresponding destruction of the organic matter which the sewage brings into the stream.

G. R. R.

Report upon the Organisms, excepting the Bacteria, found in the Waters of the State (of Massachusetts)[1] *July* 1887 *to June* 1889. By G. H. Parker.

(Report of the State Board of Health of Massachusetts, U.S., p. 579.)

The samples, except in the case of those derived from water collected for chemical analysis, were obtained by straining about 15 gallons of water through a cloth tied closely to the end of a faucet; the sediment being then removed to a glass slide and

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 536.

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examined under the microscope. In the case of water destined for chemical analysis, 200 cubic centimetres were strained through cotton-cloth, tied over the stem of a common glass funnel, the sediment being then transferred to a glass slide with the necessary precautions. The service waters of Boston, Charlestown, and Cambridge were examined monthly for a period of two years, and the results of the observations are arranged in Tables. The Author points out that these Tables are of value, not only as records of the organisms present in the various samples, but they also furnish an opportunity of comparing the organisms of one year with those of another. The conclusion to be drawn from these observations is, that with certain named exceptions, the more important genera reappear in a given year in much the same order as they did in the preceding year. In a second set of Tables is shown the seasonal distribution of organisms, which are arranged according to their natural groups.

Dividing all kinds of water-supply into two sections, as "ground water," and "surface water," a further series of Tables is given to indicate the distribution of organisms in waters variously situated. These groups are again subdivided, the former into (1) Driven wells, deep filter-galleries, &c.; (2) Springs; (3) Closed reservoirs; and (4) Open reservoirs. The latter into (1) Natural ponds; (2) Artificial ponds; (3) Open reservoirs; (*a*) from natural ponds; (*b*) from artificial ponds; (*c*) from rivers and brooks; and (*d*) from partially filtered surface water; (4) Rivers; (5) Brooks; (6) Partially filtered surface water.

Dealing with the purification of water rendered foul by organic growths, the Author discusses the importance that organisms possess in their relation to certain disagreeable tastes and odours, and points out the various remedial measures that have been proposed to deal with the different kinds of organisms whose presence has been recorded in the Tables. In the case of the algæ, light is an essential element in the production of their food, and hence the absence of light determines the absence of algæ. Moreover, since the animals are dependent upon the supply of algæ for their food, it is natural that their presence should coincide very nearly with that of the algæ. Certain of the fungi can probably derive their food from very minute quantities of dissolved organic matter, or from very dilute infusions. There are reasons for believing that the crenothrix, which is present in nearly all classes of water, does not possess the power of organizing its food. The plan of dealing with ground waters is to keep them from light, and surface waters must be converted into ground waters by careful filtration, and they must then be protected from the further growth of organisms by excluding them from the light.

With respect to the growth of sponges in water-supplies, the Author prefaces his observations with a brief account of their structure and habits. The sponge spicules, which consist of flinty matter, are almost indestructible, and consequently can be

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carried long distances in currents of water. The growth of the sponge is as a rule active in summer and autumn, and it is quiescent in winter and early spring. Having discovered the spicules of the sponge in the water of Boston and Charlestown, it became a question of some interest to locate its growth. This was found to be in the principal mains, which are 12 inches in diameter; no trace of it was found in the reservoirs or in the small pipes. In attempting to find some effectual mode of checking or preventing its growth, the Author points out that sponges, together with certain animals found in the pipes (water snails), are dependent for their food upon organic matter carried to them by the water; if this is removed they die. To test the truth of this, the results are given of the growth of sponges in glass-tubes supplied in the one case with filtered, in the other case with unfiltered water. In the former case they speedily died, in the latter they remained in a flourishing condition. The Author remarks that further observations confirmatory or otherwise of this view are desirable.

G. R. R.

The Filtration of Water through Filters of Calcined Infusorial Earth. By Dr. H. NORDTMEYER.

(Zeitschrift fuer Hygiene, vol. x., 1891, p. 145.)

Attention is directed by the Author to a filter composed of a hollow cylinder formed of calcined fossil-meal, or diatomaceous earth. The manufacture of these cylinders was at first attended with considerable difficulties, but these have now been overcome. The extreme brittleness of the calcined material also offers certain objections to its use, but Mr. Berkefeld has overcome all obstacles and has produced the requisite hollow cylinders, closed at one end, from selected specially prepared fossil-meal.

The specific gravity of the denser cylinders is 0·90, but a very porous variety, which can also be made, has a specific gravity of only 0·72. Exclusive of pores the specific gravity is 2·1, so that it may be assumed that the cavities occupy 65·7 per cent. of the bulk. It is found on microscopic examination of a very thin section that these pores are extremely minute, and they are filled with very fine spiculæ, which cross one another in every direction and form a sort of delicate internal network. The substance is such a very bad conductor that it must not be exposed too suddenly to heat, and it may best be sterilized by being placed in cold water and raised to the boiling-point for three quarters of an hour. Several series of experiments with liquids containing micro-organisms, which were carried out by the Author, are detailed, the results being given in a tabular form. The parts of the

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apparatus and its construction are described by reference to a diagram. The filter is fitted up with rotary brushes to cleanse the exterior surface of the cylinder from time to time, when it is being used for very foul liquids. The Author states that the filter yields a reliable filtrate, free from germs for a lengthy period, that the germs then found are those of saprophytes, which have grown through the filter, and these may be reduced to a minimum by vigorous rinsings. It will yield a volume of 2 litres of water per minute, or an amount of filtered liquid far in excess of other domestic filters producing a filtrate free from germs. By mechanical cleansing it can always be restored to its original working condition, and it is thus capable of being used for very turbid liquids.

G. R. R.

Chemical and Bacteriological Investigation of the Röckner-Rothe System[1] *of Sewage Treatment at Potsdam.*

By B. Proskauer and Dr. Nocht.

(Zeitschrift fuer Hygiene, vol. x., 1891, p. 111.)

It is pointed out in the introduction that the object to be attained in the purification of sewage-water is the destruction of all the infectious matter contained therein. It is also necessary to effect such changes that the liquid after treatment may no longer be liable to putrefaction. The success of any process in accomplishing these results must be tested by chemical and bacteriological analyses. The chemical investigations should in the main be relied upon for the determination, quantitatively, of the amount of putrescible (organic) matters present in the sewage. The best methods of conducting the analyses by the computation of (1) the loss on combustion; (2) the amount of permanganate of potash needed to oxidize the organic matters; and (3) the total amount of nitrogen present, are described. The great differences in the results obtained in the examination and treatment of fresh sewage, and of sewage that is already partially putrid, are discussed. In addition to the above-mentioned facts it was deemed advisable, in the case of the Potsdam inquiry, to ascertain the total amount of lime and chlorine present in each sample, before and after treatment. By reference to a diagram the arrangement of the works at Potsdam is described. They consist of a siphon-well constructed to hold 8·5 cubic metres of raw sewage, a deep well to hold 28·5 cubic metres, a clarifying chamber, conical in form with the clarifying cylinder dipping into it, the latter being 2·75 metres in diameter, inclined at an angle of 60° and rising to a height of 6·5 metres above the top of the conical vessel into

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 297.

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which it dips. The mode of working the apparatus by means of a partial vacuum created in the upper part of the cylinder is explained. The Authors state that the preparation employed for the treatment of the sewage is a secret in the hands of the firm, but the composition of the reagents was disclosed to them. The only active disinfectant is quicklime, which, in the form of milk of lime, constitutes about one-fifth of the mixture. The quantity of the precipitants used is not varied in accordance with the strength of the sewage. It was found necessary to take samples of the sewage under treatment in seven different places. The results are set forth in Tables too long for abstracting. It is stated that the sewage was of a highly concentrated character, more in the nature of the contents of a cesspool than like ordinary town sewage. In order to give an idea of its composition, the sewage is compared with that of Dortmund, Essen, Berlin, and of the Schwartzkopff Works,[1] the last named being practically pail-stuff, yielding a residue on evaporation of 2,408 milligrams per litre of matters in solution, with a loss on combustion of 1,067 milligrams per litre. The Potsdam sewage contained in one trial a residue of 2,271·5 milligrams per litre, and showed a loss on combustion of 819 milligrams per litre.

The working of the process is contrasted with the corresponding figures obtained on the treatment of the sewage of Dortmund and Essen in a further Table, from which it follows that at Potsdam the residue on evaporation in the effluent was reduced from 2,271·5 milligrams to 1,844·5 milligrams, the loss on combustion from 819 milligrams to 443·5 milligrams, the oxygen required (as tested by permanganate of potash) from 975 milligrams to 546·5 milligrams, and the total nitrogen from 262·3 milligrams per litre to 169·0 milligrams; these reductions being respectively equivalent to 19, 46, 44, and 36 per cent. The amount of ammonia was increased by the process, owing no doubt to the decomposing action of the lime; and still better results were obtained towards the close of the treatment. The clarification, *i.e.*, the removal of the matters in suspension, is stated to have been completely successful; not so, however, the results, as respects the matters in solution, owing in all probability to the extremely concentrated nature of the liquid.

The chief remaining point to be ascertained was, whether the effluent, after its discharge into the River Havel, was diluted to such an extent as to be prevented from subsequent putrefaction, and whether it was likely to have any deleterious effect upon the river water. Analyses are given to show the influence of the sewage admixture upon the composition of the river-water, and the Authors affirm that it may be assumed from these that the dilution which takes place is such as to remove all danger of injury to the river.

The bacteriological examinations of the results of the process

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[1] *Post*, p. 340.

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are shown in a series of Tables, and from these it would seem that the amount of precipitants employed is insufficient to destroy all germs in the sludge and in the effluent, and that it would be necessary to make use of five times the present amount of quicklime to effectually sterilise the effluent.

G. R. R.

On the Success Attained by various Systems of Clarifying Sewage-Water at Frankfort-on-Main. By Dr. B. Lepsius.

(Deutsche Vierteljahrsschrift fuer oeffentliche Gesundheitspflege, 1891, p. 230.)

The experiments here recorded have been carried out during the past three years, at the Frankfort works, under the supervision of a Commission consisting of Dr. Spiess, Mr. Lindley, Dr. Libbertz, and the Author. Certain of the results obtained have been already published,[1] and an account of the works is there given. In all eight series of experiments have been conducted, with five different systems of clarification. The various processes investigated were as follows:—

(*a.*) Precipitation with sulphate of alumina and lime. Series I to III.

(*b.*) Precipitation with lime alone. Series IV.

(*c.*) Simple deposition, without chemicals. Series V.

(*d.*) Precipitation with sulphate of iron and lime. Series VI and VII.

(*e.*) Precipitation with phosphoric acid and lime. Series VIII.

The volume of sewage dealt with was about 30,000 cubic metres (6,600,000 gallons) per diem, and upwards of one thousand complete and comprehensive analyses were carried out.

The results of the different series of experiments are set forth in eight Tables. A second set of Tables gives comparative analyses of the sewage water and the effluent. In its mean composition the Frankfort sewage, though considerable fluctuations were observed, does not differ materially from that of other towns, London, Paris, Dantzig, Berlin and Breslau, with which it is contrasted in a special Table. By means of a set of graphic diagrams are shown the results of the various purification processes, as evidenced by the character of the effluent as compared with the raw sewage, and the Author sums up the general effect of the different modes of treatment. In all cases the suspended matters were far more efficiently dealt with than those in solution, and the appearance of the sewage water, as tested by the eye alone, was greatly improved.

Passing on to the comparative value of each of the various processes as tested by the elimination of injurious constituents, numerous

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 392.

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Tables are given to show the amounts of suspended and dissolved impurities removed by each different system, and the effect produced by the various precipitants is discussed in detail. In dealing with the amount of organic matter present, special consideration is given to the phosphoric-acid treatment, and a graphic diagram is appended to show the proportion of the phosphates removed at each different stage of the process, and carried off in the effluent. From this it appears that though all the added phosphoric acid is expended in enriching the sludge, the amount of phosphoric acid present in the deposit from untreated sewage is nearly twice as great as is that in the sludge from the phosphate process. The figures in milligrams per litre are as follows :—

Phosphoric Acid Originally Present.		*Phosphoric Acid after Treatment.*	
1. In raw sewage.	67·4	1. In deposit in sand chamber .	29·4
		2. In sludge	17·4
2. Added to secure precipitate.	17·6	3. In effluent	38·2
Total. .	85·0	Total. .	85·0

Hence, instead of securing a sludge valuable for agriculture, more than twice the quantity of the phosphoric acid employed for the precipitation is carried away in the effluent, viz., 38·2 milligrams per litre, of which about half is in suspension, and half in solution. The Author points out that from this aspect it would be better not to treat the sewage with phosphate of lime at all, but to clarify it by simple deposition, and then to add the phosphate to the sludge.

In conclusion, it is stated that the experiments have demonstrated that the effect of chemical precipitation is not so greatly superior to the purification obtained by simple deposition in tanks, as to warrant the adoption of any of the above processes in preference to simple mechanical treatment. This, of course, does not hold good for sewage treatment generally, but it applies only to the conditions prevalent in the present works. It is proved, however, that in every case where tanks approaching the dimensions of those at Frankfort are available, more especially where the length of the tanks is equally great, it is possible to obtain, by purely mechanical means, results comparing favourably with the clarification attained elsewhere in tanks of smaller size only by means of chemical treatment, and therefore at a greater cost.

G. R. R.

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The Schwartzkopff System of Sewage-Treatment[1] *(Berlin).*

By B. PROSKAUER.

(Zeitschrift fuer Hygiene, vol. x. 1891, p. 51.)

The Berlin University Hygienic Institute having been requested to report on the Schwartzkopff process, to decide upon the extent to which the offensive constituents of fecal matters were eliminated by this system of treatment, the necessary bacteriological researches were entrusted to Dr. Plagge and Dr. Petri, under the superintendence of Dr. Koch; and the Author was instructed to undertake the chemical investigations, and to report generally upon the experiments. The machine factory where the system is in use contained a set of water-closets, dry-closets, and urinals, resorted to daily by about seven hundred workpeople. The cesspit of the water-closets receives also the liquids from the urinals, which are flushed with water. The fecal matters are raised from the cesspit into a mixing tank close alongside, where they are pulped by mechanical means and mixed with chemicals which consist of:—1. Milk of lime; 2. Solution of sulphate of magnesia; 3. Solution of crude superphosphate; 4. Solution of chloride of magnesium.

These substances are added separately in tanks provided with stirring apparatus, and they are apportioned by small metal cups attached to an endless band. After this treatment, the mixture passes along an open channel into one or the other of a set of three depositing tanks, where the solids subside, and a tolerably clear liquid is decanted off and passed through a peat-filter. The sludge is also run on to a layer of peat to drain, and when all the liquid has been strained away, it is converted into poudrette manure in a special apparatus at a temperature of 70° Centigrade. The clear liquid from the filters is allowed to flow into the sewers.

Eleven different samples were needed in order to complete the inquiry, viz., the fecal matters from each description of closet, the mixture of excreta in the tank before and after the addition of the chemicals, the supernatant fluid and the sludge from the depositing tanks, the peat and the filtered liquid, the sludge and the liquid draining from the same, and the poudrette. The Author describes the mode of taking the samples, and the way in which the chemical analyses were conducted. The results are set forth in a tabulated form. The nature of the action of the precipitants, and the relative quantities of each substance employed are also inquired into. Three different sets of experiments were carried out, for reasons which are explained. A corresponding series of bacteriological investigations of the products obtained at each different stage of the process was conducted in the institute, and the number of

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 527.

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germs present, which range from one hundred and fifty millions per cubic centimetre in the fecal matters in the dry-closet to twenty thousand in the unused peat, are shown in a Table. Each of the three sets of observations are described in detail, together with certain side issues, which arose out of the inquiry, viz., the disinfecting action of each of the different kinds of chemicals, and the extent to which the clarified effluent is liable to undergo further putrefaction. The general results of the investigation are summed up in a series of eleven conclusions, from which it follows that the process is capable of completely removing all suspended matters; but it produces but little effect upon the soluble ingredients, especially the nitrogenous substances and the ammonia. The chemical action is almost entirely due to the added lime. The treatment has a certain disinfecting action upon the sewage, and leads to a most marked reduction of the micro-organisms in the effluent; the sludge, on the contrary, remains in this respect but little affected. Other conclusions have reference to the liability of the effluent to putrefy, and to the imperfect degree of disinfection attained in the case of the poudrette. It is laid down that the effluent should not, without further treatment, be passed into the sewers, and the peat-filtration process is declared to be a disadvantage rather than otherwise.

G. R. R.

The Disinfection of Dwelling-houses in the City of Berlin.

By H. MERKE.

(Deutsche Vierteljahrsschrift fuer oeffentliche Gesundheitspflege, 1891, p. 253.)

By a decree of the Police authorities of Berlin, dated February 7, 1887, it was rendered compulsory to disinfect the dwellings as well as the effects of patients suffering from a lengthy category of infectious disorders. Not only were the clothes, bedding, and all articles used by the sick person to be operated upon, but the walls of the sick chamber were to be rubbed down with bread as prescribed by Pistor, this plan being preferred to the use of the corrosive sublimate spray which was advocated by the Author, and all the furniture was to undergo special treatment. The house disinfection is carried out upon a plan devised by the Author, by the experienced trained staff. It was arranged that the services of a certain number of work-people should be obtained from an existing society upon a fixed payment of six marks per head per diem. These men had to receive special instruction under Mr. Göldner to qualify them for their duties, and they were furnished with the requisite appliances, chemicals, &c. The precautions to be observed in the case of utensils, polished furniture, floors, &c., are laid down. All fabrics, bedding, clothing, &c., are packed up by the workmen, and disinfected by steam at the

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central station. In certain cases respirators of peculiar construction are worn by the operatives. The official instructions for the work are printed in full, and a list is given of sixty-three articles of dress, pieces of apparatus, &c., required by the staff. A tariff has been drawn up for the payments to be made for the work. Statistics are given of the number of rooms and dwellings operated upon, and of the cubic contents of the fabrics, &c., disinfected at different dates.

G. R. R.

Pastore's Water-Meter for Minimized Loss of Pressure.

L. Decugis.

(L'Ingegneria Civile e le Arti industriali, 1891, p. 12.)

This measuring- and registering-apparatus for the feed of water to boilers or other vessels is the invention of the late Luigi Pastore. It is simple in arrangement, and solid in construction, and gives a continuous record with great exactitude.

It consists in its essential parts of a distributing-cylinder and a measuring-cylinder placed parallel and vertically. The former, which is of small diameter, contains a quadruple piston, covering an inlet and outlet, and two ports communicating with the measuring-cylinder. The space above the upper piston communicates with the inlet and with the outer air, the second with the inlet, the third with the outlet, and the fourth always with the outer air.

The measuring-cylinder is divided into two parts by a piston with a central diaphragm and very broad ring, the rod being packed with glands of exceptional length. Practically perfect hermetical closing is thus secured. The upper part of the piston-rod is provided with a rack-edge, working direct on to the wheels of the registering-dial.

Assuming, at the commencement of the flow of water through the apparatus, that the multiple-piston in the distributing-cylinder is at the top of its stroke, and that the upper space is thus in communication with the air, the lower port is open to the parallel measuring-cylinder, and the upper port to the outlet; thus the water passes into the lower portion of the measuring-cylinder, forcing the piston upwards and ejecting any water from the upper portion until at the close of the stroke a small disk on the piston-rod strikes the short arm of a reversing-lever, which immediately lowers the piston in the distributing-cylinder. In its new position the upper space is closed to the air and opened to the inlet, and the upper port is opened, so that the water fills the upper portion of the measuring-cylinder, forcing down the piston and ejecting the water below through the lower port and the third space to the outlet, until at the bottom of the

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stroke the piston-rod disk again strikes a lower coupled arm of the reversing-lever, and the action is repeated as before. Every portion of the cylinder and piston is of metal, and the apparatus can therefore be used for water at any temperature.

The indicator registers the number of strokes made, so that to arrive at the quantity, say, in gallons, supplied to the boiler the coefficient must be in terms of the capacity of the measuring, cylinder. Representing by V and V_1, respectively, the upper and lower portions of the cylinder, each stroke = $V + V_1$, and with n strokes, recording N units on the indicator, the volume C =

$$\frac{n\,(V + V_1)}{N}$$

By careful experiment the apparatus has been tested to register within 0·75 per 1,000 of the water actually passing through to the boiler.

P. W. B.

Apparatus for the Prevention of the Waste of Water in Closets and from Taps. By THOMAS GOODSON, of Berlin.

(Gesundheits-Ingenieur, 1891, p. 223.)

By means of diagrams a contrivance is explained for the prevention of the use of an excessive amount of water for flushing purposes. A double valve is inserted in the supply-pipe, and the parts of the valve are so arranged that the weight on the seat of the user of the closet, communicated by a spindle, opens a valve, and admits the high-pressure service-water into an air-vessel placed alongside the closet basin. Into this air-chamber the water flows, compressing the air until the pressure is equalized. On rising from the seat a second valve is opened, the supply is cut off, and the water collected in the air-vessel is forcibly ejected into the basin, and serves to flush out the contents. The amount of water passing into the air-vessel can be regulated by means of a screw which admits of the adjustment of the volume of compressed air. This apparatus has the advantage of not being liable to freeze in the winter time, and, as the air-vessel fills slowly, some considerable time must elapse between each flush. A somewhat similar arrangement of valves can be applied to ordinary house-taps, and by this means it becomes possible to arrange for the withdrawal of only a given volume of water at each opening of the tap. This contrivance, which the Author calls a "Neptune tap," is explained by diagrams.

G. R. R.

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Pumping-Stations and Reservoirs lately erected for the Improvement of the Paris Water-Supply. By — BECHMANN.

(Annales des Ponts et Chaussées, Feb. 1891, p. 233.)

The water-supply of Paris is divided into two distinct services, one for the streets, yards, stables, gardens, and industrial purposes, and the other for house-supply. For the domestic supply the pure and fresh spring-waters of the Vanne and Dhuis are led from their source to covered reservoirs by closed aqueducts, and conveyed to the consumer without contamination; while the public service is supplied by the waters of the Seine, the Marne, and the Canal de l'Ourcq (which is also used for navigation), and there are some other sources, including Artesian wells.

In 1878 these combined resources were equal to a maximum daily yield of 270,000 cubic metres for the public service, and 127,000 cubic metres for domestic supply, the total of 397,000 being equivalent to 198 litres per head of the population of two millions. The works for obtaining this supply comprised the Artesian wells, the Aqueducts (old and new), and twelve pumping-stations working at a total of 2,130 HP. (measured in useful work), the motive power being derived from fourteen steam engines and twelve hydraulic engines disposed at the different stations; while the storage reservoirs were thirteen in number, containing 331,000 cubic metres of water for domestic supply, and 103,000 cubic metres for the public service. A certain portion of the supply thus obtained is pumped again to four high-level reservoirs, having a total capacity of 28,670 cubic metres, for the supply of the highest zones of the city, by means of seven pumping-engines of 326 combined HP. distributed between three supplementary pumping-stations.

The insufficiency of this system of water-supply had already been recognized, and in 1879 the Municipal Council decided upon a scheme for extending the works in various directions, so as to provide a daily delivery of 70 litres of spring-water, and 200 litres of river-water per head of the increased population. The works contemplated in this programme were at once commenced, and may now be said to have been completed, although the details have in the meantime been considerably altered.

The Paper describes the works that have been actually carried out, including three new pumping-stations on the Seine, the addition of further motive power to existing stations, the collection of some other sources of spring-water, and the extension of the reservoirs.

There are now on the Seine seven pumping-stations, equipped with twenty steam-engines and thirty-nine boilers, working up to 2,400 effective HP.; on the Marne three stations, containing twelve hydraulic machines and five steam-engines with ten boilers,

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working altogether up to 1,500 HP.; and in the valley of the Vanne four stations, containing six hydraulic machines and four steam-engines working up to 450 HP. At the same time, the supplementary power for supplying the high-level reservoirs has been raised to twelve steam-engines of 632 combined HP. By means of these additions, the maximum daily supply has been raised to 145,000 cubic metres for domestic use, and 473,000 cubic metres for the public service.

Of the new pumping-stations, the most important is that at Ivry, situated on the left bank of the Seine, and just above the confluence of the Marne. The construction of the machines for this establishment was put up to competition, divided into two contracts, one for the engines and pumps, and the other for the steam-boilers. The terms of the "specification" defined the useful work for a day of twenty-four hours, viz., for the engines the pumping of 85,000 cubic metres of water to a height of 63 metres; and for the boilers the evaporation of 160,000 kilograms of water. They fixed the maximum consumption of steam in the engines at 9·95 kilograms per hour for each HP. of useful work, and the minimum production of the boilers at 7·50 kilograms per kilogram of coal (obtained from the mines of Aniche). They imposed a minimum number of independent machines, with all corresponding parts interchangeable, and prescribed some special arrangements to prevent interruption by floods; and they limited the steam-pressure to 6 kilograms, but left the design open to the competitors.

A great number of designs and tenders were received, exhibiting the widest variety in the types of engine, pumps, and boiler, all the principal types of each being represented in the competition. The arrangement of power ultimately selected from these designs comprised a series of six independent and similar condensing engines placed side by side, each engine consisting of a single horizontal steam-cylinder, with piston-rod passing through both covers and actuating on one side a rotating shaft and fly-wheel, and on the other a rocking-lever by which a pair of vertical pumps are driven, through the intervention of a rocking-beam, or rather, a pair of horizontal levers. The pumps are single-acting, the pistons being fitted with multiple valves, and are so arranged that the water traverses each pump-cylinder in succession, the two cylinders forming in effect one double-acting pump. The distribution of steam in the engine is effected by a modified form of Corliss valve-gear.

The Author describes in detail the boilers and machinery attached to this and to each of the other pumping-stations, and then passes on to a description of the new reservoirs, some of which are remarkable for the exceptional form of their construction, dictated chiefly by the nature of the foundations.

At Villejuif the reservoir is covered with a light groined vaulting resting upon masonry pillars. The foundations were of necessity laid upon the gypsum beds, and, owing to the solubility

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of the sulphate of lime, it was deemed requisite to protect the subsoil from any possibility of infiltration. With this object the floor of the reservoir has been separated from the foundations by the intervention of a network of dry galleries. The floor may be described as having a thickness of 2·30 metres of masonry, but pierced by a series of flat elliptical galleries, crossing each other at right angles, and following the lines of the reservoir arching above. The inverts of these galleries, as well as the floor of the reservoir, are covered with a rendering of Portland cement; and they serve to drain away any infiltration from the reservoir, as well as forming a means of access and inspection, and a convenient receptacle for the several mains and pipes.

At Grenelle is another reservoir destined for the storage of river-water, and therefore not covered. Here the foundations presented some difficulty, owing to the fact that the ground had been disturbed to a great depth by quarrying. The floor of the reservoir has been constructed upon semicircular groined arches resting upon pillars of masonry, which have been sunk through the disturbed ground in the form of square or rectangular wells having a height of nearly 12 metres and a diameter of 2 metres. The arches are at some height above the ground, and form a dry crypt beneath the floor of the reservoir.

At Montmartre the new reservoir may be described as a three-storey building, or as consisting of three reservoirs superposed one over the other, in addition to an underground basement or dry crypt beneath the whole. Of the three reservoirs, the lowest is devoted to the storage of river-water, the second contains spring-water for the supply of the surrounding district; while the third storey, which only extends over a portion of the building, supplies a narrow zone of the district which is above the reach of the other. The floor of each reservoir forms the covering of the one below, and is carried upon groined arching supported upon masonry pillars, whose sectional area is, of course, increased in each descending storey of the building. The entire structure is founded upon the sand overlying the marl and gypsum beds; and the weight is distributed over the whole area of the foundation by the thick masonry floor which encloses the galleries of the dry crypt. This floor has a height of 3·40 metres from the foundation level to the bottom of the lowest reservoir, and is pierced by arched galleries crossing each other at right angles and having a width of 2 metres at the springing, and a clear height of 2·40 metres. The invert or floor of these dry galleries is laid in concrete and covered with a rendering of cement. Above these galleries the lowest reservoir holds a depth of 5 metres of water, and has its top-water level at 127·30. The second storey has its top-water at 132·0, and holds a depth of 3·50 metres; while the topmost reservoir has top-water level at 136·0, and contains a depth of 2·50 metres. The total capacity of the reservoir is a little more than 11,000 cubic metres.

T. C. F.

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The Water-Supply of Brussels and its Suburbs.

By JULES GERNAERT.

(L'Industrie Moderne, 1890, p. 146 *et seq.*)

An account is given of the scheme propounded by Mr. Paul Van Hoegaerden for the water-supply of Brussels and its vicinity, having a population of about 490,000 persons. The project includes the interception of the water issuing from various springs in the neighbourhood of the Castle of Modave, occupying high ground about 85 kilometres eastward of Brussels. The level of the invert at the point of departure from Modave will be 173 metres above datum, and the invert of the terminal aqueduct at Soignes will be 118 metres above datum, giving a fall of about 65 centimetres per kilometre (3·43 feet per mile) for the supply main.

The estimated yield of water per diem is 86,400 cubic metres (19,000,000 gallons), and the approximate expense of the works is stated at seventeen millions of francs (£680,000), being equivalent to a cost of 4½ centimes per cubic metre (2*d.* per thousand gallons) of daily water-supply. The hydro-geology of the district of Hoyoux, in which the springs are situated, is discussed, and the Author explains by diagrams the difference between a river basin, as defined superficially by the watershed, and the underground catchment area of water-supply, which latter depends on the conformation of the strata and the position of the impervious beds deep in the subsoil—the one he terms the "pluvio-graphic basin," the other the "hydro-graphic basin." A sketch of the geology of the Ardennes, with maps of the country during each of the great epochs is given, in order to explain the reasons for preferring the water from the vicinity of Modave to that from other districts which have been proposed.

The Author enquires into the quantity of water that is now available for the supply of Brussels, and the amount likely to be needed if the population increases in the present ratio until 1920. On December 31, 1888, the total population of the city and suburbs was 481,943, and the annual growth is set down at 9,497. It would then be necessary in 1920 to provide for a population of 785,847 inhabitants, and the water needed would—at 150 litres per head (33 gallons)—amount to 120,000 cubic metres per diem. The present supply is estimated at 35,000 cubic metres. The mode of derivation of the existing water-supply is explained, and the various plans of Messrs. Cassel & Co., Messrs. Hochereau & Mourlon, Mr. Moulan, Captain Verstraete, Messrs. Le Borgne & Pagnoul, the City Authorities of Brussels, and Messrs. Dewilde & Scoumanne are discussed in detail. In the more extended account of the scheme the subsidiary works for collecting the water from the different springs are described. These involve the construction of 3,048 metres of aqueducts, the positions of which are explained

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by reference to a plan. The altitudes of the five supplies vary from 192 to 175 metres above datum.

On chemical analysis by Mr. Depaire, the waters gave the best possible results. They are perfectly clear, colourless, and free from smell, and they are rich in dissolved oxygen. The bacteriological investigation, conducted by Dr. Malvoz, took place at the University laboratory at Liége. Samples from each spring were cultivated on Dr. Koch's system in nutritive gelatine. The volumes treated were 1 cubic centimetre, $\frac{1}{2}$ cubic centimetre, and $\frac{1}{20}$ cubic centimetre respectively. The plates cast with $\frac{1}{20}$ cubic centimetre, when examined after three days, were quite free from germs, the $\frac{1}{2}$ cubic centimetre plates contained from three to four colonies, and the 1 cubic centimetre plates from six to nine colonies. On pure cultivation all of these germs proved to be innocuous. The water may then be pronounced to be remarkably free from micro-organisms. The total contents being about 9,000 germs per litre as compared with from 60,000 to 80,000 microbes per litre in the water of the Vanne supplied to Paris. A detailed account is given of the works, aqueducts, and siphons, needed to convey the water to an elevated covered reservoir in two divisions, each capable of holding 20,000 cubic metres of water, situated at Boitsfort. The sill of the reservoir would be 110 or 112 metres above datum (sea-level), and the water-pressure would enable the authorities to obtain motive power at a very cheap rate. Dividing the inhabited area into three zones, the lowest at an average elevation of 25 metres above datum, the second at an elevation of 55 metres, and the third at 70 metres above datum, the Author shows that in the first the water might be delivered at a mean pressure equivalent to a head of about 65 metres, in the second at a head of 45 metres, and in the third at, say 35 metres pressure. With a full reservoir the pressure would be further increased in each case by 6·50 metres. The price of horse-power and the price per candle-power of electric light by the use of the Modave water is next discussed; the value of the water being taken at 9 centimes per cubic metre (4*d.* per 1,000 gallons), the price of one horse-power per hour in each of the three zones is estimated at 0·54 franc, 0·63 franc, and 0·99 franc respectively.

These prices are contrasted with hydraulic power in London, where water is supplied at a pressure of 50 atmospheres, at charges which indicate a cost of from 0·60 franc to 1·61 franc per horse-power per hour. A series of general conclusions is appended to the report, setting forth the advantages likely to arise from the execution of the work.

G. R. R.

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Comparison of Water-Supply Systems from a Financial Point of View. J. Leland Fitzgerald.

(Transactions of the American Society of Civil Engineers, 1891, p. 247.)

The data upon which this Paper is based were collected to prove the comparative efficiency of the three general systems of water-supply. The results are set down by the Author in tabular form. Table 1 gives an outline of the works in all towns in the United States, having, in 1880, a population of over 15,000. The chief of these appear in the subjoined summary :—

System I.—Pumping to Reservoir.

City or Town.	Estimated Population.	Date of Construction of Water-works.	Length of Mains.	Number of Taps.	Pressure in Lbs.	Daily Consumption.	Total Cost of Works +3,650.	Daily Working Expenses.	Total Cost per 1,000 Gallons.
			Miles.			Gallons.	£	£	d.
Cincinnati .	275,000	1820	247	31,128	100	32,079,000	442·39	154·16	4·55
Baltimore .	400,000	1807	358	66,089	60	34,000,000	613·77	60·16	4·80
Pittsburg .	215,000	1826	175	16,000	70	30,000,000	254·00	110·82	2·95
Brooklyn .	770,000	1856	397	79,073	40	46,278,000	738·62	328·62	5·60
Philadelphia	1,000,000	1800	876	163,816	20	88,850,000	845·62	332·92	3·20
Boston . .	400,000	1848	574	72,039	38	37,481,000	1,194·33	279·21	9·60
St. Louis .	450,000	1830	315	34,022	40	31,500,000	732·87	152·32	6·80
San Francisco	250,000	1856	250	26,000	60	19,112,000	958·37	451·00	18·00
Detroit . .	200,000	1836	323	32,938	25	36,079,000	230·62	60·27	1·95
Cleveland .	230,000	1854	252	22,658	40	22,266,000	305·45	50·64	3·90
Milwaukee .	185,000	1872	148	14,072	38	20,089,000	169·94	67·45	2·85
Allegheny .	80,000	1847	27	3,300	40	17,824,000	92·25	50·84	1·95
Omaha . .	100,000	1880	75	3,500	100	7,500,000	169·12	25·42	6·30
Jersey City .	155,000	1852	160	16,936	40	16,500,000	279·21	303·81	8·60
Richmond .	85,000	1830	73	8,900	41	11,133,000	84·66	17·22	2·20
Louisville .	165,000	1857	137	11,001	35	10,307,000	411·64	33·42	7·50
Nashville .	80,000	1832	42	4,321	35	8,523,000	112·75	24·40	3·90
Newark .	160,000	1800	161	12,207	23	12,642,000	150·47	58·22	4·05
Lowell . .	70,000	1872	83	7,440	60	4,319,000	240·67	18·86	14·70
Providence .	125,000	1870	202	13,128	39	4,925,000	351·37	39·36	19·45
Toledo . .	80,000	1873	56	2,875	50	3,700,000	70·52	12·92	5·50
Hoboken .	75,000	1855	78	5,559	40	4,250,000	54·94	30·55	4·85
New Orleans	230,000	1833	72	4,400	25	6,000,000	135·10	22·35	6·40

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SYSTEM II.—DIRECT PUMPING.

City or Town.	Estimated Population.	Date of Construction of Water-works.	Length of Mains.	Number of Taps.	Pressure in Lbs.	Daily Consumption.	Total Cost of Works + 3,650.	Daily Working Expenses.	Total Cost per 1,000 Gallons.
			Miles.			Gallons.	£	£	d.
Chicago .	775,000	1852	638	100,000	25	91,648,000	642·06	577·77	3·20
Buffalo .	250,000	1852	250	29,467	30	38,485,000	253·79	71·55	2·10
Kansas City	110,000	1873	85	7,786	90	10,000,000	253·79	31·57	6·95
Minneapolis	160,000	1867	112	5,598	80	10,814,000	80·15	38·33	2·60
Columbus .	95,000	1870	70	5,207	70	5,816,000	65·40	17·22	3·45
Savannah .	52,000	1853	33	2,850	30	5,715,000	17·02	7·38	1·05
Evansville	60,000	1870	33	2,230	40	4,000,000	28·29	22·34	3·10
Dayton .	55,000	1869	37	1,799	35	2,755,000	11·27	3·07	1·35
Atalanta .	66,000	1874	27	2,000	40	1,575,000	25·62	10·04	5·40

SYSTEM III.—GRAVITY.

New York.	1,700,000	1835	620	180,000	10	110,000,000	2,248·85	336·02	5·75
Washington	160,000	1853	128	22,095	20	26,148,000	479·29	7·79	4·55
Troy . .	60,000	1880	53	5,250	60	8,000,000	66·01	28·70	2·90
Worcester .	79,500	1852	110	8,110	100	4,000,000	98·81	53·10	9·25
Springfield	40,000	1873	81	4,819	90	4,000,000	75·23	14·15	5·45
Hartford .	48,000	1854	80	5,836	60	5,000,000	95·73	15·99	5·45
Portland .	34,000	1867	96	6,425	60	5,000,000	84·66	8·20	4·55
Rochester .	130,000	1872	216	17,000	40	7,200,000	217·92	17·02	8·00
Reading .	60,000	1865	59	21,940	50	4,000,000	65·60	8·20	4·50

The column of date covers, in some cases, the practical reconstruction and remodelling of older systems. It will be noticed that the Author assumes ten years as the virtual life of any system, estimating that this allowance covers the average reconstruction of the system once in every twenty to thirty years, payment of interest at from 3 to 7 per cent., and a life of pipes not exceeding twenty years. The pressure is an important factor, on which is mainly dependent the difference between a small fire and a great conflagration. A low head for service, as at New York, involves enormous individual expenditure.

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With respect to comparative efficiency the three chief systems are averaged as under:—

Basis of Comparison.	Pumping to Reservoir.	Direct Pumping.	Gravity.
1. With regard to first cost alone .	6·85	8·54	5·14
2. „ „ working expenses alone	22·30	23·21	35·46
3. With regard to combined expenses of interest, sinking fund, and maintenance. . .	4·85	5·94	4·16

The total average cost per 1,000 gallons is:—

	d.
By pumping to reservoir	5·88
„ direct pumping	4·80
„ gravity	8·55

or without Altoona, where the cost attains the exceptional figure of 3*s.* 4½*d.* per 1,000 gallons, average = 6*d.*

It will be seen that the gravity- and reservoir-systems are about equal in cost, and that direct pumping has an advantage of about 20 per cent. The efficiency of the latter is independent of the age of the works and the original cost, and increases in direct ratio to the consumption; the efficiency of the former varies inversely with the age of the works, the size of the town, the daily consumption, and the original cost.

The Author gives, also in tabular form, the distribution of cost in many instances under the heads of interest, administration and superintendence, general repairs and maintenance, &c.

TABLE SHOWING NUMBER OF WATER-WORKS BUILT IN THE UNITED STATES.

Date.	Gravity.	Direct Pumping.	Pumping to Reservoir.	Pumping to Stand-Pipe.	Pumping to Tank.	Total Number.
Before 1840 . . .	15	1	7	..	2	25
From 1840 to 1849 .	4	..	10	..	..	14
„ 1850 „ 1859 .	22	3	15	1	1	42
„ 1860 „ 1864 .	17	1	2	1	..	21
„ 1865 „ 1869 .	36	10	18	1	2	67
„ 1870 „ 1874 .	69	42	43	8	10	172
„ 1875 „ 1879 .	63	33	54	17	26	193
In 1880	17	8	7	3	..	35
„ 1881	16	7	11	4	5	43
„ 1882	24	23	13	15	11	86
„ 1883	27	14	13	14	16	84
„ 1884	25	19	30	19	19	112
„ 1885	25	21	22	15	18	101
„ 1886	24	20	38	36	21	139
„ 1887	35	22	27	60	25	169
„ 1888	38	26	40	81	53	238
Total . . .	457	250	350	275	209	1,541

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Table No. 3 (subjoined) is a brief historical summary. The gravity systems gradually dwindle in number, chiefly, doubtless, because all cheaply-available supplies were secured long since. The number of reservoir systems does not show great variation. Direct pumping came into favour about 1870, though at first it was generally regarded as a mere makeshift necessitated by the circumstances of general financial depression and the high prices of materials. Its chief disadvantage is apparent when the consumption is small.

The arguments in favour of a reservoir system as against direct pumping may be summarized as:—

(1) Better protection against fire, by storage of large quantity of water.

(2) Greater economy in working expenses.

(3) Purer water obtained by filtration and settlement in reservoir.

These conditions are, of course, open to considerable modifications according to the chemical or mechanical composition of the water and to climatic conditions.

The Author's conclusions are that a gravity system is naturally the most efficient where the supply is pure, fairly abundant, and accessible without works of too costly a nature; that direct pumping is the most economical when the daily consumption exceeds 500,000 gallons, and where there is no great difference of level for distribution; and that where part of the district is at a considerable elevation a reservoir with independent-force main is the best adapted for the purpose.

P. W. B.

The Quantity of Water Available in Sandy Soils, and its Utilization for the Supply of Towns. By T. Stang.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1890, p. 69.)

In dealing with sandy soils, on this occasion, the downs along the coast of the North Sea are specially considered. This formation is eminently favourable for the collection of water for supply to towns. The sandy downs are less subject to contamination than other soils, for two reasons: First, the very slight influence of animal life; and secondly, the great oxidizing power of sand.

The district under consideration can be divided into two categories, the natural downs or sandy hills, and the parts levelled by digging away the hills. From this last kind of gathering-ground, water of a slightly yellow colour is obtained, which, however, can easily be made colourless by chemical means or by mixing with the clearer water from the hilly parts.

Objection has been sometimes made to the use of water from

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the low-lying parts; but, according to the investigations of Dr. Josef Fodor, of Buda-Pesth, unnecessarily so, as the oxidation or nitrification of water by percolating through sand, destroys very rapidly any organic matter contained in it. It may be, therefore, admitted, that at a certain depth beneath the cultivated surface, nothing is found of the contamination consequent on agriculture, large accumulations of manure or other organic remains excepted.

According to observations on the gathering-ground for the water-supply of the Hague, about 30 to 50 per cent. of the rainfall can be collected. The variation in quantity is owing principally to the season in which the rains fall. In summer a great deal is absorbed by vegetation, and does not, therefore, penetrate into the soil, as is the case during the winter months, when also no loss is caused through evaporation.

The sand downs have a great power of attracting atmospheric vapour not precipitated in the form of rain. After long droughts, sand at a slight depth on the hill-tops is found to be damp, which cannot be ascribed to capillarity, as lower surfaces are dry to greater depths at such times.

The most advantageous system of obtaining the water contained in this sand formation is by covered porous drains, which supply the pump-wells. In these enclosed conduits air or sunlight cannot penetrate, and no development of organic life need be feared.

To obviate the choking of the pump-valves by sand, the suction-pipes are laid in a column of shells. This allows the water to flow from the pipes or conduits in a slow and constant motion, and preventing any too strong and localized currents acting on the surrounding sand.

The Paper is illustrated by several diagrams.

H. S.

The Drainage of the Lake in the Tedingerbroek, Holland.

By P. A. KOREVAER.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1891, p. 221.)

The lake near Stompwijk had formerly an area of about 500 hectares (1,250 acres). The railway embankment of the Gouda-Hague line—constructed in 1870—divides the lake and contiguous polder in two parts. With a view of concentrating the proposed pumping-power in one engine, proposals were made to the railway company to obtain a waterway through the embankment, but without avail. This necessitated the division of the area proposed to be drained in two systems. One of an area of 310 hectares (775 acres), to which was added part of the polder aready drained, containing an area of 500 hectares (1,250 acres),

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and the other of an area of 190 hectares. The drainage of this last part was to be discharged into the draining-trenches of the old polder, and had to be lifted to a height of 3·25 metres (about 11 feet), requiring 16 HP. to operate an Archimedian screw of 5 feet diameter, inclined at an angle of 30°, at forty revolutions per minute. The engine required for the larger area required 69 HP. and worked two kinds of pumps. For the deepest part of the drained area, the old lake, two double suction- and pressure-pumps were chosen, with a diameter of 1·075 metres (about 42 inches), and 1 metre, or 40 inches stroke, working at 10½ strokes per minute. For the old polder land, a water-wheel was preferred of 6·6 metres diameter (20 feet), 1 metre (3 feet 4 inches), immersion under normal lower water surface, 8 inches wide, and 6¾ revolutions per minute. These engines were amply sufficient for the eventual drainage. No infiltration from surrounding lands was experienced, and only rainfall had to be dealt with. The reclamation required three months of continuous pumping.

The Paper is accompanied by a drawing.

H. S.

Works on the Marne and Saône Canal. By A. FLORENTIN.

(Les Annales des Travaux Publics, 1891, p. 89.)

The Marne and Saône Canal is destined, in the Author's opinion, to become the chief waterway connecting the north of France with the south and south-east; the distance by this route between Saint Quentin and Châlons-sur-Saône—the two common terminal points—being 420 miles (counting each lock as 0·62 mile), as against 591 miles by the Burgundy Canal, and 573½ miles by the Canal du Centre. The canal passes through an important industrial and metallurgical region, and will therefore without doubt secure a considerable local traffic. The project was first studied about sixty years since, and a portion known as the Canal de la Haute Marne, from Vitry-le-Français to Chamouilly, and subsequently to Rouvroy—a length of about 48 miles—was constructed before 1870; the remainder was deferred on account of the greater exigency of other frontier communications, but was taken in hand in 1879, being only further delayed by the reduction of public expenditure in 1884.

The Canal branches off from the Marne at Vitry-le-Français and ascends the Marne valley by Saint Dizier, Joinville, Bologne, Chaumont, and Langres, to the summit section of 6¼ miles (of which 5,274 yards is in tunnel), at a height of 820 feet on the Marne side (the summit being at 1,118 feet), and terminating at 492 feet above the Saône. It descends the valley of the Vingeanne, and joins the Saône near Pontailler, about 12½ miles below Gray.

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The total length of the canal is 141 miles 3 furlongs. The depth of water is 7 feet 3 inches, and the locks have an effective length of 126 feet 4 inches, and width of 17 feet, with a fall of 12 feet on the Marne slope, and 11 feet 6 inches on the southern side; the summit section being worked either by lifts or by locks with considerable fall, and with reserve basins.

The water-supply to the canal, for locks, evaporation and filtration, is estimated as under:—

	Gallons per annum.
Working of locks at 700,000 annual tonnage (estimated 5,385 vessels at average 130 tons)	1,446,664,444
Leakage	322,222,000
Evaporation and filtration in soil	7,795,227,500
Total	9,564,113,944

This quantity (*i.e.*, twelve months' reserve) is stored in four large reservoirs, viz.:—

1. *Villegusien*, on the Saône slope	1,765,600,000 gallons.
Catchment-area	33·38 square miles.
Length of dam (earthwork)	4,000 feet.
Greatest depth of water	33 feet 6 inches.
2. *Charmes*, on the Marne slope, north-east of Langres	2,427,700,000 gallons.
Catchment-area	16·18 square miles.
Length of dam (earthwork)	1,191 feet.
Greatest depth of water	51 feet.
3. *La Liez*, on the summit section, commanding both slopes. (Constructed some years since)	3,531,200,000 gallons.
Catchment-area	13·12 square miles.
Length of dam (earthwork)	1,509 feet.
Greatest depth of water	47 feet 4 inches.
Water surface	721 acres.
4. *La Mouche* (just completed), north-west of Langres, on the Marne slope	1,920,100,000 gallons.
Catchment-area	25 square miles.
Length of dam (masonry)	1,346 feet.
Greatest depth of water	74 feet 4 inches.
Water surface	241 acres.

The La Mouche reservoir, formed on a stream of that name, in the communes of Saint Ciergues and Perrancey, is situated in the upper lias formation and on alluvial beds, and supplies the summit section of the canal, on the Marne side, by a channel 8,970 yards in length, delivering 26,484 gallons per minute. The dam is built of masonry, forming on plan a straight line 1,346 feet in length, and carried to a height of 6 feet 9 inches above the water-level, with parapets 3 feet 5½ inches in height. The dam serves also to carry the highway, which formerly traversed the site of the reservoir; this is effected by a semi-viaduct, the piers of which spring from the curved face of the dam, the arches

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carrying the road and footway (22 feet 8 inches wide between parapets). The thickness of the masonry at water-level is 11 feet 6 inches, the internal face having a batter of 1 in 50, the outer face being vertical to a depth of 14 feet 9 inches, followed by tangential curves of 22·96 and 180·45 feet radius respectively. At the toe and heel and one intermediate point there is a lower belt of masonry about 6 feet deep, serving to anchor the mass more securely against any lateral movement. The weight on foundations is limited to 5½ tons per square foot. The central portion of the foundations was put in without any hitch; but on the hillside, on the right bank, the excavation had to stand open throughout the winter, the result of which was that a slip of about 260,000 cubic yards occurred, destroying most of the work in the trench. The subsequent operations, involving excavation to a depth of 60 feet in the water-logged marl, were carried on only under the protection of intricate shoring of great strength (baulks 16 inches in diameter having been crushed), but happily without further accident. Great difficulty was also experienced on the left bank, where a watercourse had its channel. The hillside was set in motion, threatening many houses as well as the high road; but a number of masonry spurs were built across the trench at intervals of 6 feet 6 inches, in masonry in cement-mortar, the intervening spaces being then filled in with masonry. This work was rapidly carried out, and successfully arrested further movement.

All materials were obtained from the adjoining limestone quarries of Fontaine-au-Bassin; and the débris, crushed and sifted, was used as sand. Experiments on the tensile resistance of the mortar showed a strength of 142 lbs. per square inch for the mixture of Cruas lime and crushed limestone sand, as against 114 lbs. per square inch for the same lime with siliceous sand. In the foundations the mortar was composed of 858 lbs. of hydraulic lime to 35½ cubic feet of the above sand; and in the upper part of the dam, 770 lbs. of Cruas lime to the same quantity of sand. The total quantity of masonry was 313,000 cubic yards, of which 183,000 was in foundations. The bywash and sluices are constructed to discharge 358,637,500 gallons in twenty-four hours.

P. W. B.

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Hydraulic Work and Inland Navigation in Italy: Administrative Regulations and Methods of Construction.

By Enrico Manara.

(Il Politecnico, 1890, pp. 573, 655; 1891, p. 33.)

This memorandum, extending over a series of Papers, was prepared officially under the supervision of the Author, for the information of the Russian Government as to the river navigation of Italy, the steps adopted to improve navigable channels, the works undertaken for irrigation or for protection from inundations, and the financial arrangements laid down by the Italian Government.

Section 1 contains a summary of the laws and regulations affecting the subject.

Section 2 defines the classification of public hydraulic works, which are dealt with in four categories, viz.:—

(1) Works in the exclusive charge of the State, *e.g.*, waterways forming a connected system of navigation—rivers, lakes, and trunk canals—and frontier or boundary streams.

(2) Works carried out and maintained by the State in co-operation with the Provincial Councils and interested parties (landowners), *e.g.*, works along embanked rivers and their tributaries from the point where the embankment commences; also canals for local navigation not forming part of any through system.

(3) Works carried out by a council of the interested parties, *e.g.*, works on open (not embanked) streams and tributaries for the protection of common and exclusive interests. In such cases the State may contribute not more than one-fourth of the cost when the works are useful for navigation purposes, or directly assist the safety of national property. The Provincial Councils also contribute proportionally.

(4) Works carried out exclusively by the riparian owners, *e.g.*, small works enclosing particular lands, subject to civil rights of enforcing co-operation of any other parties benefited by such works.

The Italian Legislature acts throughout on the principle that the expense is chargeable to those benefited in proportion to the value of their interests, whether to the State, the province, the municipality, or the individual, or collectively or individually.

Section 3 gives the details of the administrative arrangements and the duties of the department of the Ministry of Public Works, which has the control of hydraulic works, the whole kingdom being divided into twelve hydraulic districts, the limits of which are defined by the watersheds. Each district has its own staff of officials and workmen. In the matter of legal restrictions it is absolutely forbidden:—

(1) To interfere with the roots or trunks of any trees upon the

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banks of streams or torrents within a distance of 30 feet from the normal water-line.

(2) To plant any trees or shrubs upon the dams or embankments of rivers, torrents, or navigable canals.

(3) To excavate any ground within the limit of 13 feet from the water-line for planting trees, or 32 feet for foundation purposes.

(4) To carry out any work which will in any way affect the condition, form, dimensions, strength, or adaptability of any existing works, or to alter any works.

(5) To pasture or maintain cattle on the banks or river works.

The following may be done by authority from the Prefect:—

(1) The formation of embankments within the limits of the normal channel.

(2) The clearance of wooded ground or underground within 330 feet from the normal water-line, subject to the previous reservation; also, subject to the same.

(3) The plantation of banks opposite points threatened with erosion.

(4) The formation of approach roads to any embankment.

By permission of the Minister of Public Works new sluices may be constructed or old ones demolished.

Navigation is the principal object with which the water system is supervised, other objects being generally subordinated. On the lakes, rivers, and natural water-courses, navigation is free, but special regulations are in force on the various canals and artificial channels. Steam navigation requires a special concession from the Ministry of Public Works. Mills and factories are allowed to draw off water only on submitting to the Government proof that so doing will not be prejudicial to navigation or to the interests of other parties. Special regulations are in force in relation to bridges, ferries, and floating-bridges, also to rafts. Considerable lengths of some of the rivers are too shallow for ordinary craft, and timber is floated down in large rafts. This requires a special licence, and is carried out under strict regulations, due notice having to be published beforehand in each district to be traversed.

The next section comprises a description of the various classes of works involved in the river defences. The Author gives a detailed description of the various parts of a dam or embankment, and of its construction. The material should be carefully selected, not too sandy nor too argillaceous, and should be spread in layers not exceeding 8 to 12 inches in thickness, each well worked down by the tipping carts or by ramming, and well wetted occasionally, work being suspended in very dry weather. The finished slopes are planted with grass. The greatest example of river-embankment is the Po, the dams of which extend on each side for nearly 300 miles. The work was commenced in Etruscan times, continued by the Romans, and completed to the sea as early as the thirteenth century.

The slopes of the banks are protected in a variety of ways:—

(1) *Piani di rosta*, layers of timber, bound with twigs, laid

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between double rows of piles parallel with the current, covered with a sprinkling of earth, then another layer of timber, and so upward. Below low-water level (*piani morti*) oak or elm is used; above this, in *piani vivi*, willow is preferred.

(2) *Buzzoni*, cylinders about 16 inches in diameter, and from 6 to 10 feet in length, formed of a nucleus of brick or stone wrapped in straw, outside which are small willow or poplar logs, the whole bound with willow swathes.

(3) *Gabbioni*, similar to the preceding, but about twice the diameter and 13 feet long; not much used.

(4) *Burghe a calcestruzzo*, similar to the *Buzzoni*, bedded on concrete.

(5) *Mantellatura*, similar protection on the inner slope.

(6) *Volpastri*, bundles of earth swathed up, for filling up gaps or breaches.

(7) *Palizzate* (piling), sheet or open.

(8) *Passaglioni* or *sieponi tessuti*, rows of open willow piling as groynes, to obstruct the current and promote silting.

(9) *Imboschimento*, or plantation of willow saplings parallel with the bank, for the same purpose. When planted obliquely they are known as *schivardoni*.

(10) *Sassaie* or *scogliere*, stone banks or facings.

(11) *Ciuffatte*, trees felled and thrown into the water and secured to the bank; bags of earth thrown in amongst the branches to form a solid obstruction.

(12) *Pennello* or *repellente*, a groyne of masonry or *gabbioni* or timber piling, or of *fascine* and earth.

(13) *Scarico*, *sgravio*, or *ributto*, trimming off the front slope and setting back the embankment.

Permanent works are next described, various typical examples being given. Of sluices descriptions are given of those at Beccara Nuova on the Reno (Province of Bologna), the outfall sluice at Burana, on the Panaro (Province of Modena), and the drainage sluices on the Reno, in the Province of Ravenna. The weirs of Gamberini on the Santerno (Province Ravenna), of Cotignola on the Senio, and of San Giacomo on the Lamone, both in the same province, are fully described; and a general notice is given of the three weirs at Bassanello, on the Bacchiglione, in the Province of Padua; also of the flood weirs on the same river at the point where it is crossed by the road from Padua to Monselice; of the regulating weir on the "Tronco Comune," and of a weir on the Canal Battaglia. Culverts on a large scale are illustrated by that on the Panaro at Burana, which has two openings 13 feet 9 inches in width and 9 feet 4 inches in height, with a length of 325 feet 3 inches; also by the works at Le Tresse, under the Brenta and Bacchiglione. No types of bridges are given, as their construction presents no special features; but the Author emphasizes the special care required in the case of embanked rivers to allow ample waterway, and not to interfere with the strength of the dams.

P. W. B.

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The Regulation and Maintenance of Inland Navigation in Italy.

(Giornale del Genio Civile, 1891, p. 85.)

The inland navigation system of Italy may be said to date from the twelfth century, the epoch at which many of the "navigli" or navigable canals of Lombardy—canals which are still in use—were constructed. The natural conditions of the Po basin necessitated the earliest development of systematic treatment both for navigation and for irrigation, and this network of waterways afforded the chief means of communication for all commercial purposes throughout the Middle Ages and until the first half of the present century. Water transit was then almost universally abandoned for railways, but in recent years it has considerably revived, and a steam-service now exists from Venice to Milan and Lake Maggiore by the Po, and, by the Tiber, from Rome to Leghorn and Genoa. In round figures the annual tonnage on some of the chief waterways is as follows:—

Po	765,000	
Adige	240,000	
Mincio	123,000	
Ticino and Lake Maggiore	186,000	also passenger-traffic =
Lake Como	130,000	1,500,000 persons.

On the chief canal systems, the Naviglio Grande (Milan) and its connections—in all 79·36 miles in length—carries 364,000 tons, the canals from Padua to Venice 377,000 tons, and the canals converging on Brondolo 950,000 tons. The Sotto Battaglia and Cagnola canals convey 196,000 tons; the Sile 465,000; and the Piave 268,000; while other canals bring up the total length to 260 miles with a tonnage of 3,130,000 per annum. Adding the river and lake traffic, the total amounts to nearly 6,000,000 tons per annum, *i.e.*, more than one-fourth of the whole traffic of the kingdom.

The Paper is accompanied by a map showing the rivers and canals in three classes, indicated by varied signs and colouring. Rivers and canals included in:

Class 1 are those navigable channels which have a depth of at least 6·56 feet, and are open all the year round.

Class 2, channels from 6·56 to 3·28 feet in depth.

Class 3, all other channels navigable occasionally or at varying periods.

These statistics are embodied in the subjoined Tables, of which No. 1 refers to rivers (natural and canalized channels), and No. 2 to canals. The column "class" of Navigable Channel refers to the preceding definition. Further data are supplied as to the hydraulic conditions and commercial development of each river and canal.

In addition to the channels thus described as "navigable"

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there are other lengths of river available for rafts, and which may be described as "floatable." Amongst these may be enumerated:—

On the	Tagliamento	about 85 miles.
„	Piave	„ 40 „
„	Brenta	„ 100 „
„	Adige	(A considerable length beyond the frontier.)
„	Po and Dora Riparia	about 80 miles.
„	Adda	„ 130 „
„	Secchia	„ 40 „
„	Panaro	„ 15 „

The general system of inland navigation is under Government control, a measure which, under the conditions of the great watershed of the Po, is essential to the maintenance of the security and fertility of the land.

The Author gives a summary of the staff arrangements of the "hydraulic districts," and a brief analysis of the expenditure of the department, which is allotted under the two heads of "extra-ordinary" and "ordinary" expenditure. "Extra-ordinary" expenditure comprises all new works and extensive repairs—items, that is, which are not continually recurrent. As recent examples may be cited:—

	£
Improvement of navigable channel of Ticino from Sesto Calende to Tornavento	19,000
Regulation of Mincio and various improvement works	14,250
„ canals in province Padua (Roncajette, Pontelongo, and Cagnola)	5,850
Regulation of canals of Morozzo and Magnavacca	13,900
„ various parts of Po, Gorzone, Brenta, Sile, Piave, Livenza, and Tagliamento	88,000

Works on the Tiber improvement; for which the parliamentary vote of over £4,000,000 has been already about half appropriated.

"Ordinary" expenditure covers all that is required in ordinary current maintenance of (1) works of art; (2) dams and roads; (3) channel. The roadway ("*viâ alzaia*") on the summit of a river dam is fixed by law at a minimum width of 16·5 feet; on certain canals in the Milan district it is from 20 to 23 feet wide, and on the Tiber from 29·5 to 33 feet. The roadway, which is usually on the summit of the dam, but sometimes on the space ("*golena*"), between the normal edge of the water and the foot of the dam, is seldom metalled on the rivers, but generally so constructed on canals, involving, in the latter case, considerable expense of maintenance. In connection with the embanked channels of some portions of the Po and its tributaries, it must be borne in mind that the water-level is in places over 20 feet above the level of the surrounding country.

Details are given of various methods usually adopted for scouring and cleaning the bed of the channels, the most primitive being that in use on the Pontine canals, where weeds grow quickly and luxuriantly in a tangled mass, and are beaten down and torn

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TABLE I.—STATISTICS OF TH

Name of River.	Total Length.	Class.	Navigable Channel (Normal).						
			Length.	Minimum Depth.	Minimum Width.			No. of Bridges.	No. Loch and Weir
					Surface.	Bottom.	At Bridges.		
	Miles.		Miles.	Feet.	Feet.	Feet.	Ft. Ins.		
Ausa	13·64	1	13·64	9·84	98	65	..	..	..
Corno	14·88	1	7·44	8·20	65	65	..	..	..
Stella	34·66	1	17·86	16·40	164	131	..	..	..
Tagliamento . .	105·40	1	11·97	8·20	295	262	..	..	..
Lemene	32·24	2	15·50	4·92	40	26	33 0	2	..
Livenza	93·00	2	48·36	6·56	197	82	..	..	..
Meduna, tributary .	60·76	2	12·40	6·00	98	82	..	..	..
Noncello „ .	11·16	3	5·21	3·00	65	65	..	..	..
Piave.	136·40	1	21·08	16·40	230	131	230 0	..	..
Sile	59·46	Pt. 1 „ 3	47·74	4·92	65	40	65 6	2	..
Brenta[1]	107·88	2	7·44	3·28	185	131	20 4	1	1
Bacchiglione[1] . .	72·54	2	33·48	3·94	131	108	22 11½	6	8
Gorzone	34·93	2	34·93	4·26	46	26	18 0½	17	..
Adige	254·20	3	(1) To Legnago— 80·00	2·13	328	262	229 8	15	..
„	..	2	(2) Legnago to sea— 51·46	5·91	262	223	29 6	6	..
Tartaro	50·22	1	18·95	8·20	98	59	70 6	5	..
Po	410·64	3	(1) 13·64	2·62	328	164	..	..	..

con

[1] The lower portion of these rivers, beyond

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NAVIGABLE RIVERS OF ITALY.

Hydraulic Data.			Commercial Data.				Remarks.	
Maximum Inclination.	Maximum Surface Velocity.		Maximum Tonnage of Vessels.	Average Annual Traffic.	Freight per Ton per Mile.		Water at or Above Normal Height, *i.e.*, Navigation Free.	Water Below Normal Height, or Navigation Otherwise Impeded.
	Ordinary.	Flood.			Up.	Down.		
	Feet per Second.			Tons.	*d.*	*d.*		
1/17,000	0·59	0·82	60	6,600	..	0·61	Free all year round, with exception of few days occasionally.	
1/20,000	0·56	0·82	60	19,360	0·77	0·61		
1/50,000	0·49	..	100	6,700	0·61	0·47		
1/8,800	0·82	..	40	2,000	1·09	0·77		
1/33,000	1·64	3·28	60	12,000	0·94	0·47		
1/1,000	6·23	8·20	100	50,000	0·94	0·47	Free all year round.	
1/1,700	3·15	3·94	70	19,000	0·77	0·77		
1/1,700	2·62	..	70	26,000	0·77	0·77		
1/1,700	6·56	..	100	268,000	0·94	0·47		
1/3,300	1·77	5·05	100	250,000	0·24	0·08		
1/2,800	1·57	6·56	70	5,000	1·88	1·09	April to Dec.	Jan. to March.
1/2,300	2·49	3·12	50	2,400	1·88	1·09	Free all	year round.
1/3,300	1·47	..	30	9,600	1·54	1·54	March, June, Oct., Dec.	January, July to Sept.
1/770	8·20	16·40	75	up 700 / down 167,000	0·94	0·77	April to Nov.	Jan., March, December.
1/4,200	3·94	6·23	150	up 13,840 / down 58,000	1·41	0·94		
1/11,000	1·31	1·64	20	2,955	0·77	0·77	Sept. to June.	July, August.
..	..	..	..	(6,500)	variable.		March to July. Sept. to Nov.	..

the lengths quoted, is in artificial channels.

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TABLE I.—

Name of River.	Total Length.	Class.	Navigable Channel (Normal).						
			Length.	Minimum Depth.	Minimum Width.			No. of Bridges.	No. of Locks and Weirs.
					Surface.	Bottom.	At Bridges.		
	Miles.		Miles.	Feet.	Feet.	Feet.	Ft. Ins.		
Po	..	2	(2) 93·00	4·92	492	394	98 6	3	..
„	..	1	(3) 230·02	2·62	656	492	229 8	6	..
Po di Goro . . .	31·00	3	31·00	3·28	197	197	..	..	..
Mincio	44·64	1	13·21	9·84	124	92	88 7	2	2
Oglio.	101·70	3	(1) 15·50	2·62	164	131	16 5	?	..
„	..	2	(2) 26·04	5·25	213	197	19 8	4	..
Adda.	160·60	3	(1) 16·10	2·95	164	98	..	..	..
„	..	2	(3)[2] 6·35	2·95	..	..	..	..	..
„	..	3	(5) 6·45	3·12	328	262	..	..	..
Ticino	..	2	(1) 15·00	3·61	262	131	361 0	1	..
„	[2]86·92	3	(3)[4] 13·64	1·31	262	131	426 6	1	..
„	..	2	(4) 4·77	4·92	393	295	374 0	1	..
Secchia[1]. . . .	105·40	1	7·32	6·56	98	82	114 10	1	..
Panaro	102·26	3	35·34	3·28	148	49	78 9	1	..
Reno.	136·40	2	24·5	6·30	115	92	32 9	1	..
Arno	153·76	Pt. 3 „ 2	65·66	4·92	328	197	82 0	23	1
Tiber.	248·00	Pt. 3 „ 2 „ 1	89·28	3·94	262	197	242 9	10	..

[1] The lower portion of these rivers, beyond the lengths quoted, is in artificial channels.
[2] From frontier only.

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continued.

Hydraulic Data.			Commercial Data.				Remarks.	
Maximum inclination.	Maximum Surface Velocity.		Maximum Tonnage of Vessels.	Average Annual Traffic.	Freight per Ton per Mile.		Water at or Above Normal Height, i.e., Navigation Free.	Water Below Normal Height, or Navigation Otherwise Impeded.
	Ordinary.	Flood.			Up.	Down.		
	Feet per Second.			Tons.	*d.*	*d.*		
1/2,500	3·28	10·83	70	19,000	0·94	0·61	Free all year round except in floods.	
1/1,800	3·28	5·91	200	820,500	1·41	0·94		
1/1,000	0·98	6·23	..	very irregular			May, June, Oct., Nov.	..
1/15,000	1·97	..	175	up 17,700 down 106,000	1·70	1·41	..	Jan., Feb., Aug., Dec.
1/1,000	2·95	3·94	30	variable				
1/5,000	2·30	3·12	130	4,500	1·88	1·41	..	
1/60	14·76	Navigation closed in flood.	36	30,000	..	0·16	..	
1/450	13·78		36	30,000	..	0·16	..	
1/2,600	4·26		36	13,000	..	0·16	..	
1/810	9·84	14·76	50	100,000	..	0·61	April, June, Sept., Nov.	..
1/1,200	6·56	11·48	40	up 2,500 down 58,000	1·22	0·77		
1/2,500	3·94	11·48	70	up 23,000 down 2,000	0·94	0·77		
1/4,000	..	..	200	up 7,500	1·09	0·61	May, June, Oct., Nov.	..
1/2,500	1·64	7·22	40	20,000	2·31	1·41		
1/6,500	3·31	4·69	?	1,220	5·84	5·23	Jan. to June	Sept. to Dec.
1/4,000	1·97	2·30	20	120,000	1·41	0·77	Jan. to May Oct. to Dec.	..
1/1,800	2·95	3·94	120	103,780	1·22	0·77	..	Summer.

[3] (2) and (4) intervening lengths not navigable.
[4] (2) not navigable.

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TABLE II.—STATISTICS OF THE CANAL SYSTEMS OF ITALY.

Data.	Section 1. Venetian System: Northern Section.	Section 2. Venetian System: Venice to Este.	Section 3. Venetian System: Outfall at Brondolo.	Section 4. Between the Po, Adige and Mincio.	Section 5. Between Po and Lakes Maggiore and Como.	Section 6. Province of Emilia (Right Bank of Po).	Section 7. Tuscany.	Section 8. Roman Campagna.	
Total length, miles .	39·64	59·74	68·87	122·36	92·69	127·75	36·00	115·75	
								80 m.	35·75 m.
Average depth, feet .	6·56	6·56 to 4·26	6·56 to 3·94	4·92 to 3·94	4·92 to 2·62	4·59 to 3·28	4·59 to 3·94	3·28	11·5 to 4·92
Average width—									
Surface, feet . .	39	52 to 33	59 to 39	65 to 39[2]	39	46 to 23[4]	39 to 26	26	98 to 42
Bottom „ . .	20	39 to 23	49 to 24·5	56 to 29·5	29	23 to 16	26 to 13	16·5	78 to 33
Average surface velocity, feet per second	1·97	1·48 to 3·28	0·98 to 3·28[2]	2·18 to 3·28	4·92	1·15 to 1·97[3]	0·33 to 0·72	almost nil	
Average tonnage of vessels	100	100[1]	150 (part 50)	30[2]	40	..	20		
Total annual traffic (average), tons . .	551,000	545,000	950,000	101,000	400,000	231,000	192,000	137,000	
Average freight per ton per mile—									
Up	0·94*d.*	1·22*d.*	1·41*d.*	1·41*d.*	variable	0·61*d.*	0·77*d.*-0·47*d.*	1·54*d.*	
Down	0·47*d.*	0·61*d.*	0·94*d.*	0·94*d.*	„	0·61*d.*	0·31*d.*	1·54*d.*	

[1] On 20 miles length, tonnage = 30 only.
[2] In great part affected by the tides in the Adriatic.
[3] For a length of 55½ miles, surface width = 115 feet, bottom ditto = 98 feet, and tonnage of vessels = 150.
[4] For a length of 7 miles, surface width = 131 feet, bottom ditto = 52 feet, and depth = 13·12 feet, affected by the tides in the Adriatic.

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up by driving about the bed of the canal teams of twelve or fourteen semi-wild buffaloes. About two hundred animals are thus employed.

The subjoined summary statement of expenditure for maintenance of the natural channels of inland navigation is based on the returns for the past twenty years:—

Name of River.	Length of Navigable Channel—Miles.	Average Total Expenditure per Annum.	Average per Mile per Annum.
		£	£
Lemene . . .	15·50	348·5	22·49
Livenza . . .	48·36	51·5	1·06
Piave	21·08	307·0	14·55
Sile	47·74	1,625·5	32·44
Brenta . . .	7·44	1,497·0	201·21
Bacchiglione . .	33·48	392·0	11·76
Adige	131·46	537·0	4·08
Tartaro . . .	18·95	363·0	19·15
Po	336·66	554·0	1·64
Mincio . . .	13·21	91·0	6·90
Ticino. . . .	33·41	1,978·0	59·22
Adda	28·90	1,782·0	61·66
Panaro. . . .	35·34	28·0	0·79
Arno	65·66	199·0	3·03
Tiber	89·28	3,556·0	40·00
Total. . .	926·47	13,309·5	14·36

On the lakes the cost of maintenance is very small. An average of the last ten years' maintenance expenses of the canal system, 379 miles in length, gives the following:—

	£ Per Mile per Annum.		Per Cent.
1. Works of art (sluices, weirs, culverts, bridges, &c.)	28·7	=	52·5
2. Dams, groynes, roadway, towpaths, &c.	7·1	=	12·8
3. Channel	16·6	=	30·3
4. Administration, supervision, compensations and sundries.	2·4	=	4·4
Total . . .	54·8		100·0

P. W. B.

The Abt Rack Railway. By R. Audra.

(Le Génie Civil, vol. xix., 1891, p. 85. 2 Figs.)

The details of the Abt-rack system have been fully described in the Minutes of Proceedings. The present article describes certain tests which have been made by the Cail Company in Paris, who have obtained the sole rights of manufacture in France from the

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inventor. Locomotives working on rack-railways were first brought out by Blenkinsop in 1811, but were speedily abandoned after Stephenson had made his experiments on adhesion; the idea is now being again used for grades steeper than 3 in 100, and has the following advantages:—

1. The practicability of using steep gradients without lessening the weight of the trains.

2. Cheap construction, from the absence of expensive works and from reduction in the length of the line, both leading to rapidity of execution.

3. Economy in working, since heavier trains can be drawn than upon the ordinary track.

The system described shortly consists of a track composed of ordinary rails, with a central rack of several soft-steel toothed plates placed vertically side by side, so that the teeth break joints, and the number of plates depends upon the grade of the line. The locomotive carries two independent driving gears, one of which is of the usual type and the other used solely for the rack-gear, and only employed on inclines. Each rack-plate has a corresponding toothed-wheel, and the wheels are so placed that a continuous drive on the rack is obtained. By means of this arrangement it is possible to use racks having teeth of 4·7 inches pitch, and a special part is arranged for entrance and exit. A very powerful compressed air-brake is used which consists of a reversal of motion by letting air instead of steam into the cylinder, and cooling the air by a jet of water while being compressed. The principal lines upon which the Abt system is used are:

1. The Hartz line (Brunswick), ordinary gauge. Length 18·9 miles, of which 4·34 miles are provided with rack upon eleven sections of lengths, varying between 272 yards and 1,690 yards, with grades of 4·5 and 6 per cent. This line has been working since 1885.

2. The Erzberg iron mines (Austria, on the Eisenerz-Vordenberg line), ordinary gauge. Length 12·4 miles, of which 9 miles are provided with rack-grades of 7·1 per cent. on the straight, and of 6·5 per cent. on curves of 196 yards radius, two plates, three driving axles; load drawn, 100—120 tons minimum. Began work this year.

3. Visp to Zermatt, for tourists, metre gauge. Two plates of 0·78 to 0·97 inch thick according to grade, two driving axles, grades of 12·5 per cent. mounted by trains of 45 tons, curves 65 yards radius.

4. Mendozza to Santa Rosa (South America). In construction, to be finished in 1892. Crossing the Andes, connecting Buenos Ayres and Valparaiso. Metre gauge, length of the part in the mountains 64 miles, 17·3 miles fitted with rack-grades of 8 per cent., and radii of 125 yards.

5. Diacophto to Kalavryta (Greece). Gauge 29·2 inches, grades of 14·5 per cent., curves of 87 yards radius. Rack composed of two plates 0·62 inch thick, three driving axles; load drawn,

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15 tons at 9·3 miles per hour on grades 3·5 per cent. without racks, and at a speed of 3·1 to 6·2 miles at grades of 14·5 per cent. with racks, line being partially worked.

6. State Railways in Bosnia and Herzegovina. Length 42 miles, of which 12 miles are fitted with rack of two plates in six sections, grades of 3 to 6 per cent., three driving axles. Each locomotive draws a train of 70 tons up a grade of 6 per cent. Working already begun, and to be completed this summer.

7. Central Dominican at Puerto-Plata, Saint Dominic. Now being built to Santiago. Grades of 9 per cent. with curves of 109 yards radius, gauge 29·5 inches. Load drawn, 50 tons at 9·3 miles per hour on grades of 4 per cent., and at 4·3 miles per hour on grades of 9 per cent.

8. Monte Generoso (Switzerland). Tourist line, 5·6 miles of rack, gauge 31 inches, grades from 0 to 22 per cent. with curves of 65 yards, two plates in the rack and two driving axles. Each engine draws a carriage with fifty-six passengers.

9. Rothhorn. Similar to No. 8.

10. Glion Railway. Similar to No. 8 and No. 9.

11. Puerto Cabello to Valencia (Venezuela). Metre gauge, grades of 8 per cent., radii of 125 yards, rack of three plates 0·85 inch thick, two driving axles, and load of 60 tons drawn on a grade of 8 per cent.

12. Manitou to Pikes Peak (Colorado, U.S.A.). Tourist line, starting at an elevation of 6,560 feet, and reaching an altitude of 14,170 feet, being 2,360 feet above the limit of vegetation. Fitted with rack for a distance of 9 miles, grades of 0 to 25 per cent., radii of 122 yards, two plates of 0·78 to 1·25 inch thick, three driving axles, ordinary gauge, mean speed 5 miles and a minimum speed of 3·1 miles per hour.

13. Electric Railway upon Mont Salève, metre gauge, grades of 25 per cent. with curves of 65 yards radius, length 5·6 miles, rack of two plates, 0·62 inch thick. Working for construction purposes will commence this summer, and the regular service next year.

14. Aix-les-Bains to Revard. This will be the first mountain railway constructed in France. The opening will take place in June 1892, all the metal work will arrive next August. Metre gauge, length 5·7 miles, fitted with rack the whole distance of two plates 0·97 inch thick. Each locomotive will pull a carriage containing sixty passengers.

15. De Veyrier to the peaks of Mont Salève (Franco-Swiss neutral ground). Line not yet begun.

16. Lastly the line from Cluses to Martigny, viâ Chamounix, the construction of which has been recently authorized and the works will be begun immediately.

The system is thus becoming largely used, about 247 miles being constructed, of which 121 miles are fitted with rack.

The lines referred to as 5, 7, 14, 15 and 16 have been or are to be built by the Cail Company.

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Experiments were recently made upon a special track 130 yards long upon ground on the Quai de Grenelle, the line representing the most difficult features which would be met with in practice. The train starts on the level for a few yards, an incline of 35 per cent. with a curve of 55 yards radius is then descended by means of the rack, this is followed by a straight level portion leading to a grade of 14·5 per cent. combined with a curve of 110 yards radius.

The rolling-stock which was successfully tested is intended for use on the line between Diacophto and Kalavryta.

E. R. D.

The State Railway on the West Coast of Sumatra.

By A. KUNTZE.

(Zeitschrift des Vereines deutscher Ingenieure, 1891, p. 634.)

The Dutch Government undertook the preliminary surveys for this line in 1873–75, but it was not till 1887 that the construction was commenced. Apart from improving communications in the district, the special object is to develop the Ombilin coalfields, in the Padang highlands. The line commences at Port Emma (Emmahafen), on Queen's Bay—formerly known as Brandywine Bay—about 4½ miles south of Padang; passing which place it continues to Padang Pandjang, at which point a branch extends to Fort de Kock, while the main line runs through Solok to the coalfields. The estimated cost is £11,400 per mile; the total length being 111·3 miles, of which nearly 18 miles is laid with central rack-rail. The gauge is 3 feet 6 inches. As far as Lubuk Along (24·8 miles) the line runs through the belt of fairly level plain, varying in width from 1¼ to 6 miles, between the Barissan Mountains and the Indian Ocean; but at this point the ascent commences, Kajutanam (36·6 miles) being at a height of 472·5 feet, and Padang Pandjang (46·5 miles) at 2,536 feet. The line to Fort de Kock (58·3 miles), attaining a height of 3,018·5 feet, runs through a narrow valley between mountains rising to a further height of 7,000 feet. The further portion of the main line descends to Batutabal (58·3 miles) at the northern end of Lake Singkarah, which is reached at an altitude of 1,214 feet; the line skirting the lake at the same level to Singkarah (70·7 miles), then rising to Solok (1,273 feet), beyond which is the summit level (1,365 feet). A descent to Muara Kalaban and final rise to Lunto brings the line to a termination at a length of 96·7 miles, and at a height of 876 feet.

The following are the maximum gradients and minimum curves:—

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I.

Ordinary Adhesion Sections of Line.	Maximum Gradient.		Minimum Radius of Curves in Chains.
	With Load.	Against Load.	
Port Emma to Kajutanam	1 in 170	1 in 85	10
Batutabal to Solok . .	1 in 100	1 in 100	10
Solok to Muara Kalaban .	1 in 50	1 in 66	7½
Muara Kalaban to Lunto .	1 in 55	1 in 33	7½

II.

Combined Rack-rail and Adhesion Sections of Line.	Adhesion only.		Rack-rail.	
	Maximum Gradient.	Minimum Curve Chains.	Maximum Gradient.	Minimum Curve Chains.
Kajutanam to Kandang Ampat . .	1 in 42	10	1 in 19·6	25
Kandang Ampat to Padang Pandjang	..	..	1 in 14·3	7½
Padang Pandjang to Batutabal . .	1 in 77	10	1 in 20	10
Padang Pandjang to Kottabaru . .	1 in 42	7½	1 in 12·5	7½
Kottabaru to Fort de Kock . . .	1 in 42	10	1 in 15	10

The central rack-rail is laid in fourteen places, varying in length from 10·8 chains to 267·6 chains, the total length being 17 miles 72 chains. In curves of more than 27½ chains radius the super-elevation of the outer rail is the same on adhesion- and on rack-rails; in smaller curves the super-elevation is about 30 to 50 per cent. higher on rack lengths than on the ordinary rails.

Very few brick bridges have been built, most of the works being in iron. The following have been erected, viz.:—

Five	164	feet span.
Twelve	131	feet, 3 inches span.
Seven	98	„ 6 „
Four	82	„ span.
Twenty-four	65	„ 6 inches span.
Forty	49	„ 6 „

and a considerable number of smaller spans.

The most important structure is a girder bridge of 183 feet 9 inches span over the Anei, between Kampong-Tengah and Padang Pandjang, on a gradient of 1 in 14·7; the height to rail-level from the bed of the river is 118 feet.

The earthworks are occasionally heavy, the deepest cutting being 72 feet, while the maximum height of embankment is

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62 feet. There is only one short tunnel (74 yards) on the portion of line already opened, but a longer tunnel (900 yards) beyond Muara Kalaban is now in course of construction.

The permanent way is of iron and steel throughout; the steel rails being rolled in lengths of 23 feet, weight 52 lbs. per yard, and the sleepers of cast steel, 6 feet 3 inches in length, and weighing each 86·4 lbs. The rack is constructed on the Riggenbach system, modified and improved; the teeth are calculated for a pressure of 7·86 tons, with a pitch of $4\frac{5}{16}$ inches, height $1\frac{3}{8}$ inch, and thickness or pitch line $1\frac{3}{8}$ inch. The rail weighs 115 lbs. per yard, and is made in lengths of 11 feet 6 inches, and secured to the sleepers by cast-iron chairs.

The rolling-stock comprises six two-coupled engines with bogie frames, the weight with tender, in working order, being 19·5 tons; two more of the same pattern are ordered, as well as six three-coupled engines, weighing 34 tons each. There are also four engines for combined adhesion and rack-gearing; the total weight of each is $26\frac{1}{4}$ tons, of which $19\frac{1}{4}$ tons is on the coupled axles. The pinion wheel is $38\frac{3}{8}$ inches in diameter. Eleven more of these engines are ordered. The carriages and wagons have a wheel base of 10 feet, the wheels being 2 feet 6 inches in diameter; the iron frames in all cases are similar, and continuous brakes are fitted throughout, the engines being fitted with the additional brakes as usual for rack-working. All working parts of the machinery and rolling stock in general are simplified as far as possible, only a few Europeans being employed—more particularly for supervision of maintenance and repairs—the bulk of the drivers, stokers, and other men being natives or Chinese. On the rack lengths the engine is attached to the lower end of the train.

The schedule of working conditions is briefly stated:—

	Weight of Train, Including Engine.		Average Speed in Miles per Hour.			
	Tons.					
Between Padang and Lubuk Along . .	180		21·70			
Between Lubuk Along and Kajutanam . .	Up. 90	Down. 180	17·36			
			Up.		Down.	
Between Kajutanam and Padang Pandjang	65	90	Ordinary. 9·30	Rack. 5·58 to 7·32	Ordinary. 9·30	Rack. 7·32

Most of the material and rolling-stock was obtained from German, Dutch, and Belgian firms. The traffic being in excess of what was originally estimated for, provision is at present required for additional equipment of the line.

P. W. B.

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Street Tramway in Berne, on the Mékarski System.

By A. BERTSCHINGER.

(Schweizerische Bauzeitung, 1890, p. 154.)

This tramway was opened on the 1st October, 1890, being worked by the Mékarski compressed-air system.

The amount of the contract was £16,400 (410,000 francs), which was to include the construction of a length of about 1·82 mile (2,927 metres) of tramway, and the provision of the rolling-stock, the line to be completed ready for opening on the 1st January, 1890. The non-fulfilment of the latter stipulation was principally due to difficulties in regard to the engines.

The general course of the line is tolerably direct. At both ends of the line there are turntables of 10 feet diameter for the engines, which always travel head forward.

A diagram of the longitudinal section of the line is given; there is a difference in level between the two ends of 111 feet 6 inches, which would give a mean grade in the length of 1·82 mile, of 1 in 86; there is, however, a gradient of 1 in 19¼, extending over a length of 142 yards.

The track is 3 feet 3⅜ inches (1 metre) gauge, and the rails, of steel, are in 32 feet 10 inches (10 metres) lengths, weighing 66½ lbs. per yard run; their cross section and the method of fishing the joints is shown by a diagram, the weight of the permanent way is 125·4 tons per mile.

The adoption of the Mékarski compressed-air system, in use for some years at Nantes and recently established on the Vincennes, Nogent, and Ville-Evrard Tramway, was due to the steepness of the street grades preventing the use of horse-traction, and as being the most suitable for the particular situation after due consideration had been given to various other possible methods of working, including the subway cable and electricity. The Author enters upon a review of the principles upon which this system is based, one of the main objects being to prevent the temperature being lowered to an unworkable degree during the expansion of the compressed air, this being effected by passing the compressed air on its way to the working cylinders through a vessel of water maintained at a high temperature.

Although at Vincennes the air is compressed to 661 lbs. per square inch (45 atmospheres), it was thought that in this instance a pressure of 441 lbs. would be sufficient; it is remarked, however, in the course of the Paper, that under certain conditions this has not been found satisfactory on the steeper grades.

A diagram elevation, plan, and cross-section, is given of the combined passenger-car and engine. There is sitting room

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within the car for sixteen passengers, and standing room for twelve persons on the tail platform. On the front or driver's platform is the air-warming apparatus (*waerme kessel*), holding 22 gallons, of which a diagram section is given, and through which the compressed air is passed on its way from the reservoirs to either the working cylinders or to the air-brake cylinders with which each car is fitted, in addition to the ordinary hand-brake. The warmer is of $13\frac{3}{4}$ inches internal diameter, formed of $\frac{3}{8}$-inch plate, jacketed to prevent radiation, and provided with a safety-valve loaded to the maximum working pressure of 176 lbs. per square inch (12 atmospheres). A detailed description is given of the various regulating valves. The air-reservoirs or holders in each automobile were in the first instance ten in number, of $17\frac{3}{4}$ inches internal diameter, and of varying lengths, with a total content of $64\frac{1}{4}$ cubic feet; they were of $\frac{5}{16}$-inch plate, with riveted joints tested hydraulically to a pressure of 588 lbs. per square inch (40 atmospheres), and the warmer to a pressure of 735 lbs. (50 atmospheres) per square inch; it was, however, found desirable to supplement these holders by two additional tubular reservoirs each with a content of 8·8 cubic feet. The diameter of the working-cylinders is $5\frac{1}{8}$ inches, with a piston stroke of $8\frac{5}{8}$ inches, the diameter of the wheels being $27\frac{1}{2}$ inches. The weight of the automobile in running trim is 6·89 tons, to which has to be added the weight of twenty-eight passengers and two attendants, at, say 165 lbs. each, or a total of 9·1 tons.

A full description is given of the turbines from which the power is derived for compressing the air, and of the compressors.

As regards the working of the traffic, the time occupied in traversing the whole length is about twenty minutes including stoppages.

The cars commence running at 6.30 A.M., and cease at 10.50 P.M. The number of outward and return journeys of $3\frac{3}{4}$ miles (6 kilometres) is 84, or a daily total of 313 miles (504 kilometres).

A Table is given showing the time occupied between various points upon the route, and the pressure in the reservoirs on the outward and return journeys, as also the consumption of air.

The speed is limited to $7\frac{1}{2}$ miles per hour for the town portion of the route, and $9\frac{1}{3}$ miles for the suburban portion.

The traffic receipts have hitherto been in excess of the original estimate.

D. G.

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Comparative Working-Expenses of Small Motors. C. KORTE.[1]

(Zeitschrift des Vereines deutscher Ingenieure, 1891, p. 39.)

The statistics embodied in this communication are the result of investigations undertaken by the Author for the purpose of fixing a tariff for the use of the municipal hydraulic mains and electric current at Barmen. It is practically impossible to give any figures capable of universal application, as the chief factor—the cost of generating the motive power—must necessarily vary according to the local prices of coal, gas, water, &c., and wages. As far as possible, however, the result has been given in general terms, with the proportion which, upon such basis, the cost of motive power alone bears to the total working expenses, so that the corresponding figure for other prices is readily obtainable.

Small motors may be divided into two categories; viz., (1) those which are worked from a central point—either under municipal or private control—and which include gas, hydraulic, electric, and compressed-air motors; and (2) those which are worked independently, viz., steam, hot-air, and petroleum engines, &c.

In estimating annual working-expenses, two examples are given, viz., for 300 days of five and ten hours respectively, or 1,500 and 3,000 hours per annum; and it is assumed that the work is performed under average fair conditions—viz., as continuous as possible and at nearly full power. In practice this is, of course, a very variable condition; and as interrupted working, or running for short periods only, naturally increases the cost, the figures represent the minimum working expenses.

With regard to the various classes of motors, it may be noted that in gas-motors ¼ and ½ HP. sizes have vertical cylinders, the larger sizes being horizontal, and more economical in consumption of gas. Comparative figures are given for four different prices for gas, viz., 2*s.* 10*d.* per 1,000 cubic feet, as at Duesseldorf, Dortmund, Elberfeld, &c.; 3*s.* 4*d.* per 1,000 cubic feet, as at Cologne, Hanover, Frankfort-on-Main, Barmen, &c. (Berlin slightly higher); 4*s.* 3*d.* per 1,000 cubic feet, as at Leipzig; 7*s.* per 1,000 cubic feet, as at Paris.

In most cases the bulk of the consumption for motors is during the daytime, and a considerable reduction—from 30 per cent. to 60 per cent.—off the price charged for lighting purposes is allowed. At Barmen, in 1884, with gas at 5*s.* per 1,000 cubic feet and no discount for motors, the annual consumption under this head was little over 4,000,000 cubic feet; but with an allowance beginning,

[1] Cf. also communication to the same Journal, p. 299, by A. Riedler.

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in 1885, at 10 per cent., and since increased to 33⅓ per cent., the present rate of consumption is over 18,000,000 cubic feet.

Hydraulic motors are based on Munich estimates, and for working at six atmospheres.

No reduction is allowed at Barmen (for which the estimate is framed) for electric current for motors, as against lighting.

The statistics for compressed-air motors are based on estimates for Paris, which are above what may be accomplished in other places; and the Author notes that these figures may be considerably reduced in consequence of recent improvements in this class of motor. In connection with steam-power it may be noted that it is placed at a considerable disadvantage by intermittent or irregular working. In the larger sizes and with regular working, and when the price of coal is not excessively high, the steam motor competes closely with the gas motor; but in the smallest sizes the gas-engine is practically the only motor to be considered. The hot-air motor is the only other system in which the working expenses compare at all with gas and steam. The Author has not investigated the cost of working petroleum motors, but considers that they have a great future before them. The cost of working hydraulic and electro-motors will doubtless in time be much reduced, when competition results in the effecting of improvements in the central distributing stations and the transmission of power. In the case of hydraulic power the working expenses may be considerably diminished when the waste water can be further utilized.

Mr. Riedler adds, in relation to the cost of the motors, comparative figures for the same machine in London, Paris, and various German towns.

Size of Motor, HP. . . .		¼		½		1		2		3	4		6	
Class of Motor.	Locality.	£	s.	£	s.	£	s.	£	s.	£	£	s.	£	s.
Gas . .	London .	33	0	60	0	80	0	120	0	155	170	0	195	0
	Paris .	38	0	60	0	88	0	112	0	130	152	0	200	0
	Cologne.	32	10	60	0	75	0	92	10	110	132	10	180	0
Compressed air . .	Paris .	157	10	232	10	385	0	461	10	538	604	10	716	10
	Augsburg	75	0	157	10	190	0	250	0	300	390	0	575	0
Steam . .	Paris .	..		..		87	0	112	0	133	167	10	200	0
	Germany	..		..		68	15	83	0	105	132	10	158	0

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TABLE I.—GAS MOTORS.

Size of Motor, HP.			¼	½	1	2	3	4	6
			£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed			38 15	68 15	84 14	104 9	124 4	149 5	202 0
Cost of working 1,500 hours, *i.e.*, 300 days at five hours, with gas at 2*s.* 10*d.* per 1,000 cubic feet. . .			11 13	16 18	21 15	32 19	43 2	54 9	75 6
Cost of working 3,000 hours, *i.e.*, 300 days at 10 hours, gas as above			16 8	23 5	30 13	49 18	66 16	85 18	119 16
Cost of gas as above in percentage of total working cost for 3,000 hours .			45	45	50	59	67	64	69
Cost per HP. per Hour.									
Price of Gas per 1,000 Cubic Feet.		Daily Work-Hours.							
	s. *d.*		*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
1	2 10	5	7·44	5·40	3·48	2·64	2·28	2·16	2·04
		10	5·28	3·72	2·40	2·04	1·80	1·68	1·56
2	3 4	5	7·92	5·76	3·72	2·88	2·52	2·40	2·28
		10	5·76	4·08	2·64	2·28	2·04	1·92	1·80
3	4 3	5	8·64	6·24	4·08	3·24	2·88	2·76	2·52
		10	6·48	4·56	3·00	2·64	2·40	2·28	2·16
4	7 0	5	11·04	7·92	5·28	4·44	3·96	3·84	3·60
		10	8·88	6·24	4·20	3·84	3·48	3·48	3·24

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TABLE II.—HYDRAULIC MOTORS.

Size of Motor, HP.			¼	½	1	2
			£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed . . .			22 10	34 13	46 18	63 6
Cost of working 300 days at five hours, water at 5½d. per 1,000 gallons			16 14	29 6	52 11	96 5
Cost of working 300 days at ten hours			28 9	52 8	96 16	181 7
Cost of supply of hydraulic power (water as above) in percentage of total working cost—						
Five hours per diem . .			67	77	83	87
Ten „ „ . .			79	86	89	93
Cost per HP. per Hour.						
Price of Water per 1,000 Gallons.		Daily Work-Hours.				
	s. d.		d.	d.	d.	d.
1	0 5½	5	10·68	9·36	8·40	7·68
		10	9·12	8·40	7·80	7·20
2	0 6½	5	12·12	10·80	9·72	9·00
		10	10·56	9·84	9·12	8·64
3	0 8	5	14·28	12·96	12·00	11·04
		10	12·72	12·00	11·28	10·56
4	1 1½	5	21·48	20·16	18·84	17·76
		10	19·92	19·20	18·24	17·28

TABLE III.—ELECTROMOTORS.

Size of Motor, HP.	¼	½	1	2	3
	£ s.	£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed . . .	18 4	23 18	28 18	40 6	50 15
Cost of working 300 days at 5 hours (at Barmen) . . .	22 10	35 15	64 1	117 16	168 9
Cost of working 300 days at 10 hours (at Barmen) . . .	41 0	66 7	121 16	226 18	340 17
Current = amperes	3	5	9·5	18	26
Cost of current in percentage of total working cost:					
At Barmen tariff, 5 hours daily	80	84	89	92	93
At Barmen tariff, 10 hours daily	88	91	94	95	96
At Berlin tariff, 5 hours daily .	67	75	82	86	87
At Berlin tariff, 10 hours daily	79	85	89	90	92
Cost per HP. per hour:	d.	d.	d.	d.	d.
At Barmen tariff, 5 hours daily	14·40	11·40	10·20	9·48	9·00
At Barmen tariff, 10 hours daily	13·08	10·56	9·72	9·12	8·64
At Berlin tariff, 5 hours daily .	8·88	7·22	5·88	5·04	4·68
At Berlin tariff, 10 hours daily	7·56	6·48	5·40	4·80	4·44

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TABLE IV.—COMPRESSED-AIR MOTORS.

Size of Motor, HP.	¼	½	1	2	3	4	6
	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed	23 4	31 18	49 3	59 13	68 17	77 8	92 1
Cost of working 300 days at 5 hours (Paris tariff) . .	23 9	36 5	52 12	87 7	112 15	136 3	160 19
Cost of working 300 days at 10 hours (Paris tariff) . .	40 15	65 2	95 10	162 18	211 15	256 12	302 18
Compressed air per HP. per hour, cubic feet . . .	2,472	2,119	1,540	1,363	1,186	1,130	883
Cost of air and fuel in percentage of total working cost:							
At 5 hours daily .	68	75	78	85	86	87	86
At 10 hours daily .	78	84	86	91	91	91	91
Cost per HP. per hour:							
	d.	d.	d.	d.	d.	d.	d.
Working 5 hours daily	15·00	11·64	8·40	6·96	6·00	5·40	4·32
Working 10 hours daily	13·08	10·44	7·68	6·48	5·64	5·16	4·08

TABLE V.—STEAM MOTORS.

Size of Motor, HP.		1	2	3	4	6
		£ s.	£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed . .		77 10	98 15	117 10	147 10	176 10
Cost of working 300 days, at 5 hours with coal at 10s. per ton		24 17	33 12	41 11	48 12	63 5
Cost of working 300 days, at 10 hours.		34 4	47 2	58 19	67 6	89 2
Cost of coal and water in percentage of total working cost: coal at 10s. per ton .		30	37	38	36	50
Cost of coal and water in percentage of total working cost: coal at 25s. per ton .		53	60	64	61·5	69
Cost per HP. per hour.						
Coal at per ton.	Daily Work-hours.					
s. d.		d.	d.	d.	d.	d.
10 0	5	3·96	2·64	2·16	1·92	1·68
10 0	10	2·76	1·92	1·56	1·32	1·20
12 6	,,	2·88	2·04	1·68	1·44	1·32
15 0	,,	3·12	2·16	1·92	1·56	1·44
17 6	,,	3·24	2·40	2·04	1·68	1·56
20 0	,,	3·48	2·52	2·16	1·92	1·68
22 6	,,	3·72	2·76	2·40	2·04	1·80
25 0	,,	3·84	2·88	2·52	2·16	1·92

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TABLE VI.—HOT-AIR MOTORS.

Size of Motor, HP.		¼	½	1	2
		£ s.	£ s.	£ s.	£ s.
Cost, inclusive of bed . . .		76 17	82 12	101 11	141 19
Cost of working 300 days at 5 hours (coal at 10s. per ton) .		16 16	19 17	26 0	38 7
Cost of working 300 days at 10 hours		19 8	23 15	32 0	48 11
Cost of coal and water in percentage of total working cost (coal at 10s. per ton), 5 hours daily)		14·5	20·5	27·0	33·5
Cost of coal and water in percentage of total working cost (coal at 10s. per ton), 10 hours daily		17·0	25·0	33·0	44·0
Cost per HP. per hour.					
Coal at per ton.	Daily Working hours.				
s. d.		d.	d.	d.	d.
10 0	5	10·80	6·36	4·20	3·12
,,	10	6·24	3·84	2·52	1·92
12 6	5	11·28	6·72	4·44	3·36
,,	10	6·48	4·08	2·76	2·16

TABLE VII.—COMPARATIVE SUMMARY OF COST PER HP. PER HOUR.

Size of Motor, HP.			¼	½	1	2	3	4	6
	Class of Motor.	Hours Daily.	d.	d.	d.	d.	d.	d.	d.
1	Gas motor (gas at 3s. 4d. per 1,000 cubic feet) .	5	7·92	5·76	3·72	2·88	2·52	2·40	2·28
		10	5·76	4·08	2·64	2·28	2·04	1·92	1·80
2	Hydraulic motor (water at 6½d. per 1,000 gallons) . . .	5	12·12	10·80	9·72	9·00	..	..	..
		10	10·56	9·84	9·12	8·64	..	..	..
3	Electro-motor (at Berlin tariff)	5	8·88	7·22	5·88	5·04	4·68	..	..
		10	7·56	6·48	5·40	4·80	4·44	..	..
4	Compressed-air motor (at Paris tariff) . . .	5	15·00	11·64	8·40	6·96	6·00	5·40	4·32
		10	13·08	10·44	7·68	6·48	5·64	5·16	4·08
5	Steam motor, with coal at 12s. 6d. per ton	5	..	..	4·20	2·88	2·40	2·04	1·80
		10	..	..	2·88	2·04	1·68	1·44	1·32
	Steam motor, with coal at 20s. per ton .	5	..	..	4·92	3·48	3·00	2·82	2·28
		10	..	..	3·48	2·52	2·16	1·92	1·68
6	Hot-air motor, with coal at 12s. 6d. per ton	5	11·28	6·72	4·44	3·36	..	..	..
		10	6·48	4·08	2·76	2·16	..	..	..

P. W. B.

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Coke-Breeze as Fuel. By G. Frère.

(Compte Rendu de la Société technique de l'Industrie du Gaz en France, 1890, p. 108.)

The increased price of coal gives a special interest to the use of poor fuels; the production of coke-breeze is increasing on account of the necessity of breaking the greater part of the coke, and it is one of those materials that it is most desirable to utilize, as it costs nothing for carriage or duty, and is in many places difficult to dispose of. The fuel value of coke-breeze depends upon its composition, which varies according to the source from which it is derived; that produced from breaking coke consists of:—

Moisture	5 per cent.
Carbon	84 „
Ashes and clinkers	11 „

and that from coke direct from the retorts:—

Moisture	13·5 per cent.
Carbon	70·0 „
Ashes and clinkers	16·5 „

The average composition of the "Pas-du-Calais" coal, generally used in the gas works of the North of France is:—

Moisture	1·5 per cent.
Carbon and volatile matters	88·0 „
Ashes and clinkers	10·5 „

Taking the percentage of carbon in each of these cases, and assuming the coal worth 16*s.* per ton, this would give the value of the breeze from the coke-breaker as equal to 15*s.* 3*d.* per ton, and that from the retorts to 12*s.* 9*d.* per ton, the lower value of the retort-breeze being chiefly due to the larger percentage of moisture it contains.

At some gas-works the coke-breeze is made into bricks to be used for generating steam or for heating the retort furnaces, but, if the breeze is worth 6*s.* to 7*s.* per ton, and its conversion into "briquettes" costs about the same sum, coal at 15*s.* per ton would be preferable, as the manufacture of "briquettes" requires expensive machinery.

The direct use of breeze as fuel has for some years attracted considerable attention, and, with special appliances, it has been utilized successfully, either alone, or with a mixture of coal. Of such appliances reference may be made to the Perret furnaces, which are now extensively used. The Cathedral of St. Quentin was heated, during the winter of 1889, by eight of these furnaces, burning only coke-breeze. The cubical contents of the church are 3,178,530 cubic feet, and during five winter months, which included sixty-five days of frost, the average temperature in the church was maintained at 52·6° Fahrenheit as compared with an

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average external temperature of 36·5° Fahrenheit. The average daily consumption of breeze was 3,053 lbs., which, at 6*s.* 5*d.* per ton, would cost 8*s.* 9*d.* per day. The system is also employed for steam-boilers.

The Author has also experimented for two years with a mixture of coke-breeze in a generator retort-furnace with the following results:—

With a mixture of half breeze and half small coal, and with the air-supply under pressure, and a consumption of 30 cwt. of the mixture per twenty-four hours, the result was unsatisfactory, as the temperature was not maintained sufficiently high for the proper carbonization of the coal. When the air-supply under pressure was done away with the furnace worked well, a slight vacuum being maintained in the generator and a slight pressure at the top of the furnace. The coke-breeze used was from the coke-breaker, on account of the smaller quantity of water it contained; the breeze was very fine, having passed through a screen perforated with about ¼ inch diameter holes. It was not considered practicable to use coke-breeze alone because it would not agglomerate, and the furnace bars would have been obstructed by it. The fuel was put into the generator every hour in quantities of 61 to 66 lbs.; twenty minutes after filling the generator, the mixture was raised with a bar and the lumps pushed to the back of the generator, the firing proceeding in a manner similar to that with coke. For one month a mixture of 40 per cent. by weight of small coal, and 60 per cent. of breeze was used, and of this, 32 lbs. were required to carbonize 220 lbs. of coal. During the next month, with 35·8 per cent. of small coal and 64·2 per cent. of breeze, the rate of consumption was 30 lbs. of fuel per 220 lbs. of coal carbonized.

The following comparisons will show the estimated cost of heating a bench of seven retorts, carbonizing 5 tons of coal in twenty-four hours, with coke or with small coal:—

	s.	*d.*	*s.*	*d.*
(1) 74½ bushels of coke at 4·36 pence. .			27	0
(2) 2204 lbs. small coal	16	0		
Extra labour	1	2½		
			17	2½
(3) 540 lbs. small coal at 16*s.*	3	11		
1003 lbs. breeze at 6*s.* 5*d.*	2	10½		
Extra labour	1	2½		
			8	0

If, as is the case in some works, the coke-breeze is of little or no value, the economy would be greater, but if, on the contrary, it can be sold for more than 6*s.* 5*d.* per ton, the economy would be proportionately reduced.

C. G.

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The Utilization of Coke-Breeze. By J. Pettré.

(Compte rendu de la Société technique de l'Industrie du Gaz en France, 1890, p. 358.)

At the meeting of the society at Paris in June, 1885, the Author read a Paper upon a system of heating gas-furnaces with coke-breeze. Since that time several such furnaces have been in use at his works, and practical results are now given showing the desirability of utilizing a product which is wasted in many places, although it contains 80 to 85 per cent. of carbon. It has been applied to benches containing seven retorts, no change being made in their disposition, except that the middle retort was removed. The furnace consists of an arch of 12 inches radius, the height from the furnace bars to the crown being 3 feet 10 inches; openings are left on each side of the arch for the passage of the flames, these openings being increased in area towards the back of the furnace. The furnace is 4 feet long and 2 feet wide, and consists of 0·315-inch bars, 0·079 inch apart, riveted together in sets of ten; they are 2 feet long, so that two sets form the length of the furnace. A false bottom in the ash-pit is supported on a ledge cast on the furnace-door frame, and on a transverse bar at the back. The space below the false bottom acts as an air-chamber, the air passing between the vertical sides of the false bottom to the furnace. A Bourdon's injector, of simple and cheap construction, is used for forcing in the air. Steam is obtained from a boiler about 98 feet distant; the steam-pipe up to the retort-house is 2 inches internal diameter, and is sufficient to supply six furnaces, the branches from it to the injectors being $\frac{1}{2}$ inch diameter. The air-supply is taken from a channel in front of the furnaces. So far it has not been found possible to use breeze alone, but where there is not an easy sale for the small coke, good results may be obtained by leaving it with the breeze. With breeze alone the quantity of clinker was so great that it formed an impenetrable layer on the furnace bars, the air-supply found passages in various parts, the combustion became imperfect, and the heats fell off.

The following proportions of various fuels were found necessary for heating a bench of retorts for twenty-four hours:—(1) 49½ bushels of coke-breeze and 16½ bushels of coke; (2) 55 bushels of coke-breeze and 13¾ bushels of small coal; (3) 30¼ bushels of small coal and 5½ bushels of coke; (4) 82½ bushels of large coke, but in cases 1, 2, and 3, only 10,582 lbs. of coal were carbonised, while in case 4 the quantity was 11,905 lbs. of coal. Also in cases 1 and 2, 2¾ bushels or 198 lbs. of small coal and 4⅛ bushels of coke-breeze were required for the production of a forced draught by steam. A breeze furnace wears out more quickly than an ordinary furnace, the additional cost for which is shown to be 13 pence per furnace per day. The breeze furnace is fired every fifteen to twenty minutes and clinkered every four

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hours, which occupies six to ten minutes, a special rake being used to push the fuel to the back of the furnace, as, without this, the clinkering would be more difficult than with an ordinary furnace. The clinkers do not adhere to the bars, but stick more firmly to the sides of the furnace; the furnace-bars are not injured, being found in the same condition when a furnace is let down as they were when put in, the air and steam keeping them always cool. It was expected that there would be deposits of ashes in the flues and chimney, but during five years' working no unusual deposits have been found.

The volume of air forced into the furnace by the injector varied between 23,993 cubic feet and 26,811 cubic feet per hour. Theoretically 1 lb. of carbon requires 142¾ cubic feet of air for complete combustion, and taking case No. 2, before referred to, the breeze and small coal would weigh about 3,417 lbs., or, deducting the residuals, the net weight of the carbon would be 2,885 lbs., and the theoretical quantity of air for this would be 411,833 cubic feet. Taking account of the partial or total stoppages for clinkering and also of the carburetted hydrogen in the small coal, it will be seen that there was not an excess of air, as, with a chimney-draught, it is generally assumed that the air necessary for combustion is double the theoretical volume.

From analyses of the products of combustion it appears that, shortly after the furnace is charged, few of the combustible elements are lost, and that a constant condition is attained until the time for clinkering, and under this condition 4 per cent. of carbonic oxide and 4 per cent. of hydrogen escape in the chimney; the absolute absence of oxygen also indicates an insufficient air-supply.

In consequence of the enormous quantities of breeze which accumulate in a gas-works with the increasing demand for broken coke, many gas-managers may be interested in the use of this system, and the selling prices of coke and breeze and the cost of coal at any works being known, a very simple calculation will enable them to decide whether there would be an advantage in doing so.

Trials were also made with firing two 30-HP. Babcock & Wilcox steam-boilers with coke-breeze and small coal, using a forced draught obtained by means of a Bourdon steam-blower. The results are given as follows:—

(1) *With small coal and breeze.*

Length of trial. . . .		10 hours.
Average steam-pressure .		6 atmospheres.
Water evaporated . . .		14,109 lbs.
Small coal used . . .	1,898 lbs.	
Breeze used	467 „	
		2,365 lbs.
Normal horse-power . .		30 HP.
Actual power developed .		42·66 HP.

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(2) *With small coal and breeze.*

Length of trial. . . .		6 hours.
Average steam-pressure .		6 atmospheres.
Water evaporated . . .		7,584 lbs.
Small coal used . . .	856 lbs.	
Breeze used	587 ,,	
	—	1,443 lbs.
Normal horse-power . .		30 HP.
Actual power developed .		36·39 HP.

(3) *With small coal and breeze.*

Length of trial. . . .		6 hours.
Average steam-pressure .		6 atmospheres.
Water evaporated . . .		5621 lbs.
Small coal used . . .	370 lbs.	
Breeze used	794 ,,	
	—	1,164 lbs.
Normal horse-power . .		30 HP.
Actual power developed .		28·33 HP.

(4) *With small coal and breeze.*

Length of trial. . . .		6 hours.
Average steam-pressure .		6 atmospheres.
Water evaporated . . .		5,556 lbs.
Small coal used . . .	326 lbs.	
Breeze used	849 ,,	
	—	1,175 lbs.
Normal horse-power . .		30 HP.
Actual power developed .		28 HP.

The proportions of small coal and breeze given in the last example may be taken as the limit for practical working.

C. G.

The Coquerel Gas-Plant. By G. Vitoux.

(Le Génie Civil, vol. xix., 1891, p. 91. 1 Fig.)

Many methods for producing gas which should act as a substitute for coal-gas have been used. The gas apparatus invented by Messrs. Coquerel Brothers employs ordinary air, which is treated with hydrocarbon in the apparatus; this consists of:—1. a motor driven by clockwork and a bellows; 2. a chamber for the primary treatment of the air; 3. a gasometer; 4. a tank for the hydrocarbon; 5. the carburetting vessels.

The air drawn in by the bellows passes first into the primary vessel, where it is subjected to a short contact with carburetting substances, and it is then led into the gasometer. Thence it passes into the carburetting vessels, which are three in number, and in which it is brought into intimate contact with the hydrocarbon. After this process it is fit to be passed into the ordinary distributing

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pipes. The feed-tank is a closed zinc vessel which contains liquid hydrocarbon, and in order to cause the flow of liquid from this tank into the carburetting vessels, the internal pressure in the tank must be at least equal to that in other parts of the apparatus; this has been very simply effected by connecting the upper part of the reservoir to the carburetting vessels. The latter consist of horizontal zinc cylinders provided with rectangular zinc boxes, which are in communication with the cylinder by means of an opening into which passes a tube for the admission of air. Inside the cylinder is a horizontal worm attached to a cylinder, concentric with that forming the casing of the vessel, and which turns freely under the pressure of the air coming in from the gasometer. A ball-cock is provided in the reservoir which keeps the level of the hydrocarbon constant in the carburetting vessels. The gas-holder is merely required to assure a pressure sufficient to cause a current of gas. The air which it contains is not combustible. The outer air is drawn in at first by the bellows, which is driven by a motor consisting of three, four or seven cylinders, which contain flat-coiled steel-springs 39·5 feet long, 4·7 inches wide, and 0·0078 inch thick, which drive a main wheel by means of gearing. This wheel drives the excentric of the bellows, by means of a train of wheels, which cause the latter to make 1,024 revolutions while the former turns once round. It is necessary to prevent the springs acting with a constant force upon the wheel, and for this purpose a friction-brake is arranged upon a wheel keyed to the shaft of the bellows, and this is applied through a system of levers when the gasometer is at its full height, so that gas is only produced at the rate at which it is being consumed.

The gas produced by this system is stated to cost about four shillings per 1,000 cubic feet, and about 2,870 cubic feet can be produced after the motor has been wound up once.

E. R. D.

On Lubrication with Mineral Oil. By — Kuntze.

(Annalen fuer Gewerbe und Bauwesen, vol. xxviii. 1891, p. 159.)

After pointing out the great changes which have taken place in the choice of materials used as lubricants in the past twenty-five years, which have resulted at the present time in the employment of 75 per cent. of mineral oil, and only about 25 per cent. of the other substances which were formerly in sole use, the Author explained the various factors which have to be studied in overcoming friction. While vegetable oils were relied upon for lubrication, the specification under which they were supplied was a simple matter. It was only necessary to stipulate that they should be of a stated variety and free from adulteration. Rape-seed oils, of whatsoever derivation, all of them had a solidifying-point at a temperature

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of from 3° to 5° Centigrade below zero, but all vegetable oils, including also olive oil, behaved in a similar way, and this question of solidification was regarded as unalterably fixed, and as a matter incapable of improvement. In a similar way all the above oils possess at a temperature of 100° Centigrade the fluidity of water, and have a flashing-point of upwards of 200° Centigrade, remaining practically unchanged at all temperatures likely to occur in bearings. The conditions were, however, entirely altered when, in consequence of economical considerations, it became necessary to introduce mineral oil; the various considerations which had to be taken into account are referred to by the Author, and the official specification which has been drawn up for the supply of oil for the Prussian State Railways is printed in full. Each clause is then discussed, and illustrations are given of the different forms of apparatus employed for testing the samples of oil for quality, fluidity, flashing-point, solidifying-point, &c. It is pointed out that much of this apparatus is still defective, and that in many cases only imperfect results are obtainable, but the Author hopes that by the attention directed to the subject it may be possible before long to effect improvements in these tests.

G. R. R.

Observations and Experiments on the Lubrication of Engines.

(Revue Maritime et Coloniale, vol. cviii., 1891, p. 554.)

In order to prevent, as far as possible, the introduction of grease into the boilers with the feed-water, it is necessary to reduce to the greatest possible extent, consistent with safety, the amount of oil used. The method of effecting this economy, some observations upon the way in which oil is carried into the boiler, its partial abstraction by the condenser, and the influence of salt upon it, form the subject of this treatise.

It is considered that the extent of surface to be lubricated in an engine of any type varies as the square of the diameter of the crank-shaft multiplied by the number of revolutions per minute, and by the number of cylinders.

In the year 1865 two-cylinder engines used 3·5 lbs. of oil per ton of coal. At the present day 6·6 lbs. of lubricant are used per ton of coal, but the ton of coal now suffices for double the amount of power.

The Author classifies existing types of engines as follows:—

	lbs. per ton.
Two-cylinder vertical engines without auxiliary engines.	4·4
" " " with " "	4·48
Three-cylinder " " " " "	6·6 to 7·3
" horizontal " " " "	6·6 to 8·8
Six-cylinder engines of the type employed in the "Duquesne" and "Eclaireur"	11·0 to 13·2

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Engines of torpedo boats, torpedo gunboats, and high speed engines for fans and electric light, use between 22 and 34 lbs. Torpedo boats with two cylinder engines at Toulon are found to use 22 lbs. of oil per ton of fuel, and those with three cylinder engines 33 lbs.

The large quantity expended in the last category is explained by inefficient utilization of the lubricant. Oil is thrown out from the joints by inertia and centrifugal force, and an excess is intentionally used in order to avoid risk of overheating, which may take place suddenly with dangerous consequences.

Different systems of lubrication are exhaustively described and illustrated, and their advantages compared. The importance of the frequent cleaning of condensers is insisted upon, and those are preferred in which the steam is inside the tubes, as affording greater facilities for cleaning.

S. W. B.

Riveted Joints in Boiler-Shells. By W. B. Le Van.

(The Journal of the Franklin Institute, May 1891, p. 335.)

Mr. Le Van adduces evidence showing that when holes are properly punched in iron or steel plates, the metal is made to flow around the punch, and is thus made denser and stronger. When the plates are very soft and ductile, the operation of punching does not do any appreciable injury to them; and he quotes the evidence of Professor Thurston, that punching is sometimes productive of an increase of strength. Punching, says the Author, possesses so many advantages over drilling, that no plate should be used in the construction of a boiler that is not improved by punching. The great objection to perforation by drilling is its relative costliness.

There is no fixed rule for the difference which should exist between the diameters of the punch and the die-hole. The maker of punches and dies generally allows a total clearance of about $\frac{3}{64}$ of an inch. The following formula is also employed:—

$$D = d + 0{\cdot}2\ t.$$

D = diameter of hole in die block in inches.
d = diameter of cutting edge of punch, in inches.
t = thickness of plate, in parts of an inch.

In which the total clearance is one-fifth of the thickness of the plates.

When the plates are punched without clearance, as in the case of cold-punched nuts, the metal is caused to flow around the punch, and is thus, as already stated, made denser and stronger. The relative strength of bars so punched, and like bars drilled, is

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shown in the following table of experimental results, contributed by Messrs. Hooper and Townsend:—

STRENGTH OF PUNCHED AND DRILLED IRON BARS.

Thickness of Bar.	Thickness Outside of Hole.	Breaking Resistance of Punched Bar.	Breaking Resistance of Drilled Bar.
Inch.	Inch.	Pounds.	Pounds.
⅜ or 0·375	⅜ or 0·375	31,740	28,000
⅜ or 0·375	⅜ or 0·375	31,380	26,950
⅝ or 0·625	¼ or 0·25	18,820	18,000
⅝ or 0·625	¼ or 0·25	18,750	17,590
⅝ or 0·625	3/16 or 0·1875	14,590	13,230
⅝ or 0·625	3/16 or 0·1875	15,420	13,750
⅝ or 0·625	⅛ or 0·125	10,670	9,320
⅝ or 0·625	⅛ or 0·125	11,730	9,580

It is shown by the results in the Table that the punched bars had the greater tensile strength, indicating that the effect of punching was to strengthen, not to weaken the metal.

D. K. C.

Testing Steel Tires. By E. ROUSSEL.

(Revue Générale des Chemins de Fer, January 1891, p. 3.)

Steel tires are subjected to three kinds of stress for testing the quality of the metal: tensile resistance of samples cut from tires, flattening tires by hydraulic pressure to the extent of one-sixth or one-seventh of the interior diameter, and submitting sample tires to shocks of a falling body. The first and second, though useful, are incomplete, whereas the trial by shock proves that the tire is capable of active resistance; and in specifying given conditions of deformation, the resisting qualities of the metal are well brought into evidence. Besides that, the shock-proof reveals defects which are not proved in the ordinary trials by tension or by compression. The metal may be rendered brittle by the presence of certain metalloids, though perfectly resisting statical stress.

To ascertain the quality of the material of which tires are manufactured, shock-trials must be in relation to the dimensions of the tires. To obtain steel of suitable hardness, the maximum deformation produced by the shock of the fall must be prescribed, also a minimum percentage of carbon. The shock is applied to the tire on edge, diametrically.

It is deduced from the tabulated results of shock-trials, that the work done on the tire diametrically compressed is independent of the diameter for a given relative deformation, which is taken as one-sixth of the diameter. Again, the work done is proportional to the modulus of flexure of the cross-section. For tires of identical section, but of different diameters, the same relative

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deformation corresponds to the same fall of the ram; and for tires of different sections, shocks proportional to the moduli of flexure cause the same deformations relatively to the diameters.

From the results of this experimental investigation, the following tests have been established on the Belgian State railways in contracts for tires: Minimum proportion of carbon, 0·30 per cent. Shock-trials, first, for tires of locomotives and tenders, three blows of the ram of 6,600 kilogrammetres (47,738 foot-pounds); second, for tires of carriages and wagons, three blows of the ram of 4,000 kilogrammetres (28,932 foot-pounds). After the second blow, the reduction of the interior vertical diameter is not to exceed one-seventh of the normal diameter; but this stipulation does not apply to wagon-tires. It is preferred that the test-tires should be selected from the same running. A maximum of 0·08 per cent. of silicon may be imposed.

D. K. C.

On Temperature-Measurements in a Bore-hole at Sauerbrunn, in Bohemia. By Dr. J. Puluj.

(Repertorium der Physik, 1891, p. 301.)

The depth of the bore is 132 metres, its upper half being lined, and from 6 metres below ground filled with water containing carbonic acid gas. The observations were made by an electrical thermometer, the variation in the resistances of a carbon filament and an iron wire with change of temperature serving by the determination on a Wheatstone bridge to give the temperature at various positions fixed by a sounding line containing the necessary conductors. The actual temperatures are plotted diagrammatically, and show that between 6 and 12 metres underground the temperature at that date (January 2nd) was practically constant, thence up to 20 metres it increased rapidly, and from 30 to 130 metres increased in an arithmetical ratio with the depth; and the temperature (Centigrade) at a given depth h (metres) may be expressed as follows:—

$$T = 11\cdot459 + 0\cdot03118\,(h - 30)$$

whence the temperature increases 1° Centigrade for each 32·07 metres of depth.

The following particulars are also given for other bore-holes; the first two columns of figures giving the depth in metres, between which the observations were made, and the last the depth in metres corresponding to a rise of 1° Centigrade.

Schladebach (near Merseburg)	6 to 1,716	36·88
Sennenitz (near Halle)	754 to 1,084	36·66
Lieth (near Altona)	426 to 1,259	35·07
Sudenburg (near Magdeburg)	30 to 568	32·36
Sperenburg (near Berlin)	220 to 1,066	32·00

F. J.

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The Florida Phosphate-Deposits. By N. H. Darton.

(American Journal of Science, vol. xli., 1891, p. 102.)

During the past year the phosphate deposits of Florida have become of considerable commercial importance. As no information is available as to their mode of occurrence, the Author has made a careful study of the principal deposits. They occur mainly in the western portion of Florida in a series of irregular areas scattered along a narrow belt for a distance of 250 miles. The entire region is not yet fully explored, and the deposits are irregular in extent and richness. The phosphates are of three classes: 1. Rock-phosphate; 2. conglomerate; and 3. river drift.

The rock-phosphate is a homogeneous light-coloured calcium phosphate, forming the surface of the middle Tertiary limestone. It is restricted to a narrow irregular belt. At Dunellon there are representative exposures in the extensive mine openings that are now being worked. The mineral is similar in texture and structure to spongy limonite, but is usually white or grey. It contains on an average 83 per cent. of calcium phosphate and 4·5 per cent. of calcium carbonate. Though not so rich as the rock-phosphate, the conglomerate phosphates occupy a considerable area in Florida. They consist of small pebbles of rock-phosphate in a soft chalky matrix, and contain on an average 76 per cent. of calcium phosphate. The river-drift deposits are of great economic importance, since they are rich in phosphate, and can be easily worked. Along the streams there are many thick deposits of this character, consisting of rock-phosphate pebbles mixed with sand. Geologically the rock-phosphates appear to be the deeply eroded remnant of the phosphatised surface of the middle Tertiary limestone; the conglomerate deposits appear to be of Miocene age, whilst the river-drift deposits are of more recent age than the Pleistocene sands that cover the entire peninsula. The origin of the calcium phosphate is not definitely known; but it is probable that guano was the original source, and that the genesis of these deposits was similar to that of the deposits of the West Indies.

B. H. B.

The Gold and Platinum Industry of the Ural. By — Laurent.

(Annales des Mines, vol. xviii., 1890, p. 537.)

Russia occupies the third place as a producer of gold in the world (the output for the year 1887 was 1,076,745 ozs.), and is the only country possessing workable deposits of platinum. The whole of the latter, as well as the best utilized if not the most

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important of the gold deposits, being contained in the region of the Ural. Their present condition is described by the Author from personal observations made during a recent voyage on the Government of Perm.

Nature of the Deposits.—The auriferous deposits have been classified by Karpinsky into primary and secondary groups. In the former gold is found either in quartzose, vein-stuff, or interspersed through the mass of crystalline rocks, such as diorite and serpentine; while the secondary deposits are auriferous sands, situated either immediately above the primitive deposits, or transported to and re-arranged at some distance from the point of origin. Platinum is only found in secondary or alluvial deposits.

The primary gold deposits of the Ural are very numerous, four groups of them being actually worked—namely, those of Berezowsk and Goroblagodask, of the district of Miask, of the Baschkir territory, and of the Orenburg Cossacks. The Author's description is confined to the Berezowsk deposits, which are the only ones that have been systematically developed to any extent. These are included in an area of about 22 square miles, in which the prevailing rocks are schists penetrated by numerous veins or dykes of a fine-grained granitic rock containing pyrites known as beresite, varying in thickness from 12 to 120 feet and upwards, many of which extend beyond the limits of the mining region.

The beresite dykes are traversed by numerous fissures filled with quartz, forming veins varying in thickness from about 10 to 70, or on an average of 30 millimetres, having a general east and west course, often uniting into groups, but never becoming parallel to the enclosing dyke. Sometimes, but rarely, they pass from the beresite into the neighbouring schistose rocks. The vein-stuff, as well as the rock, where most auriferous, is rusted from the decomposition of pyrites; the best mines yield from 1 to 1¼ oz. per ton, 10 gram (about 7 dwts.) being considered as the lowest workable limit. The pyrites is often much richer than the quartz, in some instances averaging up to 6 or 7 ozs. per ton. Below the level of decomposition of the pyrites into gozzan, or as it is locally called krassiks, the gold appears to be entirely contained in the sulphides.

The reducing-plant at Berezowsk consists of six stamp-batteries, each with five heads of 6½ cwts., making eighty lifts of 9 inches per minute. The discharge takes place through gratings with apertures of 0·01 metre[1] on to blanket sluices, 13 feet long and 2 feet wide, three of which are provided for each battery of five heads. The stamps are stopped every hour, and the blanket deposit is transferred to a second washing table or frame 6½ feet long, divided into three steps by cross riffles, where it is concentrated to a sufficiently small bulk to be easily amalgamated by hand. The amalgam when pressed dry is distilled under an iron hood heated from above and cooled by a water-jacket below,

[1] *Sic* in original; probably one millimetre is meant.

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which in a modified form represents the ancient Mexican capellina. The loss of mercury is about 12½ per cent. The slimes passing the blanket sluices are partly passed through spitzkasten and partly through pits with mechanical agitators, and then over two sieves of amalgamated copper plates before finally running to waste. The copper plates are cleaned at intervals of fifteen days by scraping. This is done by a machine having a series of knives moving alternately, horizontally and vertically, the plate as well as the amalgam removed being enclosed in a locked receptacle to prevent peculation. About 93 per cent. of the gold obtained is saved by the blanket sluices, 5½ per cent. by the first, and 1½ per cent. by the second series of amalgamated plates. The lowest working limit is 10·29 grams of gold per ton (about 6 dwts. 20 grains), and the cost about 1*s.* 1*d.* per gram, or about 11*s.* 3*d.* per ton of material stamped. The plant is driven by a 35 HP. steam-engine, peat from some alluvial workings in the neighbourhood of the mill being used as boiler fuel. The annual production is about 12,600 ozs.

Secondary Auriferous Deposits.—These, although called sands, are almost entirely clays, pure or somewhat sandy, and enclosing rolled masses and blocks of many different rocks. They are found throughout the whole Ural region over a length of more than 500 miles, having filled the valleys and forming marshy plains on both slopes of the chain, the larger development being, however, on the eastern side.

Gold is found in the alluvium in particles of all sizes up to large nuggets, accompanied by many other minerals, such as palladium, platinum, osmiridium, native copper, diamond, cinnabar, iron pyrites, magnetite, chromite, specular iron ore, rutele, brookite, anatase, corundum, garnet, and quartz. Speaking generally, the deposits associated with rocks containing hornblende and augite are richer than those in which granite and gneissic rocks prevail.

The auriferous beds vary in thickness from about 1½ to 3½ feet, in breadth from 60 to 150 feet, and exceptionally to about 300 feet, and in length from 60 or 80 feet to 1,500 feet, the direction being general parallel to that of the chain. The most extensive deposits are those of Balbuk, 2¾ miles, and Stolbuk, 3¾ miles long. The sterile covering or overburden is usually less than 13 feet, although exceptional deposits have been found at 60 and even 130 feet below the surface. The cover very frequently forms peat bogs.

The amount of gold varies from 12 to 39 grains per ton of sand (or in value from 2*s.* to 7*s.* 6*d.*), although occasionally it is double or even four times the latter amount. Nuggets are tolerably often found, the largest known one, weighing about 1,150 ozs., has been preserved in the Museum of the School of Mines at St. Petersburg.

Platiniferous Deposits.—Platinum has not up to the present time been found except in alluvial deposits, in which it is always associated with gold; sometimes the latter predominates, and th-

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platinum may not exceed 1 per cent. of the product. On the other hand, gold may at times be almost absent, and the deposits in which this condition prevails, although less abundant, are those of most value. They are confined to the districts of Nischne Tagil, Goroblagodask, and Biseik. In the first of these localities they extend for about 25 miles to the south of the village, and from the associated minerals, such as olivine and chromite, they appear to be derived from the waste of a mass of serpentine known as Mount Solvaiska or the White Mountain. The platinum is found in grains and nuggets, the largest of the latter weighing about 320 ozs. The yield varies from 39 to 195 grains per ton. The richest deposits, those of the Martiane River, are from 13 to 16 feet thick, and are covered by 60 or 70 feet of overburden chiefly consisting of clay. The conditions of occurrence in the other localities are similar to those described above, except at Goroblagodask, where the bed rock of the alluvia is limestone, but outcrops of porphyry and serpentine are found in the vicinity.

The gold deposits are partly the property of the Crown or its lessees, and partly of private individuals, but in the latter case there is often a reservation of minerals which are subjected to special royalty rents. The rate paid by the Crown lessees is from 8½ to 20 per cent., in addition to which a 3 per cent. tax is levied on all gold produced in any of the mines, the product being compulsorily saleable to the State. Platinum-working, on the contrary, is free from all taxation, and the Government monopoly of refining, which was kept up for a time, having been abandoned, the product is mostly placed in the London and Paris markets.

In working the alluvial deposits two methods are followed. In the first, the plant and apparatus are provided by the ground owner, who hires labour and directs the operations either personally or by deputy; while in the second, a system of tribute is followed, the ground being let to free workmen or *starateli*, who provide everything necessary for working, and deliver the produce at a fixed rate to the proprietor. This price may vary with the difficulty of working from 36*s.* to 42*s.* 6*d.* per oz.; but in all cases the prime cost in the proprietary workings is higher than those of the free labourers, who are able to handle to a profit stuff with from 8 to 10 grains of gold per ton. Platinum sands are considered poor when containing less than 45 grains, and rich when above 180 grains per ton. The lowest profitable limit seems to be about 39 grains. By far the larger part of the gold washing is done in the stanock or Siberian trough, an inclined washing-table varying with the fineness of the material from about 4 to 6½ feet in length, and divided into two or three parts by cross riffles. For gravel or sand a mixing box with a perforated plate is used, but muddy stuff is placed in a divided trough at the head of the table and diluted by a stream of water until sufficiently thin to flow evenly over the surface. The gold is either collected as a concentrate with the heavy minerals deposited behind the riffles, and worked up by hand, or it may be amalgamated upon the table. About 4 or

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5 cwt. of stuff is washed at a time, the loss of gold is estimated at about 2½ grains per ton. Each stanock treats about 95 cwts. of material per day, and requires four hands, one man and three women. The alluvial material is almost entirely got by open diggings, actual mining by shafts being only practised in a few places near Ekaterineborg and in the platinum deposits of Nischne Tagil. The shafts in these cases are 2 metres in diameter, the winding being effected by wooden windlasses.

At Volochanska the sands in the river-bed are worked by turning the stream, which then furnishes power for pumping the water out of the pits and supplying the washing-apparatus. The river-beds are also worked to some extent in winter by putting a tubbing through the ice and digging out the frozen ground for some distance around the bottom of the pit.

At Tcherno-Rika and Berezowsk alluvial washing is carried out on a considerable scale by a combination of sluices and blanket tables, the stuff being carried to the works by railway. A notice of the works at the former place has already appeared in the Minutes of Proceedings (Vol. xcvii. p. 490).

At Berezowsk, where there is a considerable amount of coarse material in the alluvium, it is fed into a revolving drum-sieve with ¼-inch holes, and the stones are picked over to save any fragments of quartz with visible gold, a premium of 5*d.* per gram for gold so obtained being paid to the finder. The fine stuff is washed in a sluice 35 feet long and 18 feet broad with cross riffles in the bottom 10 inches apart; from the tail of which it is lifted by an archimedean screw to a second one perpendicular in direction to the first, 50 feet long, with a slope of 1 in 5, lined with blankets at the top and sods at the bottom. From 560 to 640 tons of material are treated daily, giving 3½ tons of concentrate, which are washed and amalgamated by hand on a small table. The amalgamation is done twice daily for the deposit of the upper sluice, but only once for that of the tailings.

The power is derived from a turbine of 30 HP. driven by a head of water from the river, about 1 HP. being required for the revolving-drum, and the remainder for lifting the alluvial material from the railway to the feeding-stage, which is done by an inclined plane.

In another working at the same place, higher up the valley, where the stuff is more argillaceous, an agitator with revolving arms is substituted for the drum-sieve, but in other respects the arrangement of the sluices is similar to that last described. The daily quantity treated is 512 to 560 tons, about ten times its volume of water being required to dilute the stuff to the proper consistency.

In the working season, between May and October, about 2,500 ozs. are produced from the upper, and 1,660 ozs. from the lower washings at Berezowsk. During the winter months the operations are confined to stripping the overburden in preparation for the next season.

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Platinum Workings of Avrorinski.—These are at present the most important operations of their class. The deposits, from 13 to 16 feet thick, lie upon a conglomerate of serpentine, are covered by nearly 80 feet of dead ground, and extend for about 1½ mile, with a breadth varying between 70 and 250 feet. The average yield is about 87 grains of platinum minerals per ton, but in places it goes up to twenty, thirty, or even fifty times as much. The working is entirely subterranean, small pits 70 to 80 feet apart being sunk to the deposit, and the material, being drawn to the surface by windlasses, is washed in the ordinary Siberian frame at the mouth of the pit. About four hundred hands are employed, the work going on night and day.

The crude platinum contains about 1 part in 4,000 of gold, which is separated by amalgamation and washing with water in large capsules. The final product contains 90 per cent. of platinum.

Between October, 1886, and August, 1887, the Avrorinski washings produced from 166,023 tons of wash dirt, 948 kilograms (about 30,336 ozs.) of platinum at a cost, inclusive of all charges, of 7*s.* 2*d.* per oz., which was sold for 16*s.* per oz.

The whole of the gold produced in the Ural and Siberia is sent to the Government assay office at Ekaterineborg, where it is melted and cast into bars, the assay of which forms the basis of final settlement between the Government and the miners. The mint which formerly existed at the same place being closed, the bars are now sent to St. Petersburg for coinage. In the year 1885 about 282,000 ozs. of gold dust were melted into bars, whose average fineness varied between nine hundred and nine hundred and fifty for gold, and between fifty and seventy for silver. The loss in melting is about 4 per cent.

H. B.

A New Process for the Treatment of Cobalt Ore. By L. Pelleton.

(Le Génie Civil, vol. xviii., 1891, p. 373.)

At the works of the Maletra Chemical Company, at Petit Quérilly, near Rouen, a new process for the treatment of the cobaltic manganese ore from New Caledonia has been successfully introduced by Mr. Herrenschmidt. The composition of the ore subject to variation in certain of the less valuable constituents averages :—

Peroxide of manganese	18·00
Protoxide of cobalt	3·00
,, nickel	1·25
Peroxide of iron	30·00
Alumina	5·00
Lime and magnesia	2·00
Silica	8·00
Loss in calcination	32·75
	100·00

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The operations are entirely performed by the wet way, and the reagents used are to a large extent waste products arising in the treatment of the ore. The order of operation is as follows:—

1. *Solution of Ore.*—The ore, which is comparatively soft, is ground to a fine powder under edge-rollers, and is thrown into large pans containing a strong solution of ferrous sulphide, which is boiled by blowing steam through it. This dissolves manganese, cobalt, and nickel as sulphates; while the whole of the iron, including that in the ore, goes down as basic ferric sulphate together with the silica and alumina. The action continues for some hours, fresh ore being added as required, until the liquor when tested with permanganate is found to be free from dissolved iron. The contents of the pan are then blown over to a settling tank where the clear liquor is separated from the ferruginous precipitate. The latter is then passed through a filter process, dried, and calcined, giving a powder which is sold as colcothar.

The ferrous sulphate employed in the above operation is prepared on the spot from scrap iron and nitre cake, or the residue, consisting of sodium sulphate and sulphuric acid, obtained in the manufacture of nitric acid. This gives, in addition to the green vitriol, sodium sulphate, which salts are separated by crystallizing; the latter may also be utilized at another stage of the process.

2. *Precipitation of Nickel and Cobalt.*—The liquors containing cobalt, nickel, and manganese sulphates are transferred to stills made of slabs of the lava from Volvic, in Auvergne, and sodium sulphide is added. This precipitates cobalt and nickel as sulphides, with only a small proportion of manganese, the bulk of the latter metal remaining in solution by reason of the acidity of the liquor. The mixed sulphides when separated are treated with a solution of ferric chloride which dissolves the manganese, giving a mixture of sulphide of nickel and cobalt nearly free from foreign matters. The manganese in the still liquors is converted into chloride by chloride of calcium, and precipitated by lime to be used in the Weldon process.

The sulphide of sodium used in this operation is obtained by decomposing the sulphate of sodium remaining from the ferrous sulphate, with alkali waste in a closed vessel under pressure. The final residue of this operation being sulphate of calcium.

3. *Calcination of Cobalt and Nickel Sulphides.*—The precipitate of mixed sulphides, after the removal of the manganese, is subjected to a very careful roasting in a reverberatory furnace, which, if the operation is successful, results in its complete transformation into sulphates of cobalt and nickel soluble in water.

4. *Separation of Cobalt and Nickel.*—The product of the roasting operation No. 3, when dissolved in boiling water, is treated with chloride of calcium to convert the sulphates into chlorides, after which the liquor is divided. In one portion A, the metals are precipitated as hydrated protoxides with lime, and, after washing to remove the calcium salts, the precipitate is diffused through water, and subjected to the joint action of a current of chlorine and of

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air under pressure, with the result of forming peroxides of nickel and cobalt. A second portion B of the original protochloride liquor is then added, and the whole is energetically mixed by blowing it up with steam. This has the result of reducing the peroxide of nickel in the A precipitate, which redissolves as protochloride with the peroxidation and precipitation of an equivalent proportion of cobalt from B, so that only nickel remains in solution while the cobalt is entirely separated. The proportion of B is so chosen that the whole of the precipitated nickel is not dissolved, in order to ensure that the liquors contain no cobalt. Further additions of the solution are made in graduated quantities until the cobalt precipitate is completely free from nickel, when it is filtered, dried, and calcined for sale. The various liquors containing nickel are finally collected and treated with lime, the protoxide of nickel precipitated is separated by a filter press, and after drying and calcination is ready for reduction.

The chlorine required in the operation is obtained from a portion of the ore which is used in the stills with hydrochloric acid, in the same way as an ordinary manganese ore. Cobalt, nickel, and iron pass into solution at the same time; the first two metals are recovered, while the ferric chloride is used in the treatment of the mixed sulphides.

The works as at present arranged are equal to the treatment of about 150 tons of ore per month, which corresponds to a yield of 4,500 kilograms of cobalt oxide and 1,850 kilograms of nickel. The former is worth about 25 francs, and the latter 3·50 francs per kilogram. The annual consumption of cobalt is estimated to be above 200 tons, or a value of about £300,000.

The New Caledonian cobalt ore being very bulky it has been proposed, in order to save freight, to convert it into regulus at the mines. Experiments in this direction have been made at the same works, running down the ore with silica and iron pyrites in a water-jacket blast-furnace, with the result of producing a regulus with 8 per cent. of cobalt, in addition to iron and sulphur, and slags containing all the manganese, and only 0·02 per cent. of cobalt. This concentrated material it is proposed to treat in the same way, commencing however with operation 3, or the calcination of the mixed sulphides.

H. B.

On Desulphurizing Molten Cast-iron. By P. Tunner.

(Oesterreichische Zeitschrift fuer Berg en Huettenwesen, vol. xxxix., 1891, p. 206.)

When commercial ferrous sulphide (FeS), containing about 36 per cent. of sulphur, is melted together with ferro-manganese, the sulphur separates as a slag in the form of manganous sulphide, leaving the iron free. This reaction is utilized in a process intro-

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duced by the Hoerde Steel Works Company in Westphalia, for obtaining pig-iron for the basic Bessemer process free from sulphur; experiments having shown that fluid sulphurous metal from the blast furnace might, by the addition of highly heated melted ferro-manganese, be purified to as low as 0·01 per cent. of sulphur. The resulting manganese-sulphide slag contains 20 per cent. and above of sulphur, and about 50 per cent. of manganese, and when subjected to a reducing fusion with lime as a flux, ferro-manganese is recovered and can be applied for desulphurizing further quantities of metal. In order to carry out the operation successfully it is necessary to keep the bath liquid for a sufficient time, either by its own or externally applied heat, so that the slag may separate completely. The most convenient apparatus for the purpose is a Bessemer converter, made up without tuyeres in the bottom, and the operation should be repeated several times before pouring, in order to obtain a large volume of slag which can be then easily removed, and to promote its separation by the stirring action caused by each new addition of metal.

The results obtained at Hoerde in fifteen trials made in August and September, 1890, are given in a tabular form, from which it appears that the sulphur in metal from the blast furnace, ranging between 0·27 and 1·20 per cent., was reduced to between 0·034 and 0·056 per cent. in the purified metal for the converter, the charges being from 10 to 11 tons each. The sulphur in the finished steel was 0·018 per cent. from a metal originally containing 0·352 per cent., and 0·025 per cent. from that with 1·20 per cent. The effect of spiegeleisen and ferro-manganese as ordinarily used for recarburizing blown-metal is somewhat similar, but is less advantageous, as being likely to unduly increase the carbon or manganese on the finished steel.

H. B.

The Kassner Oxygen Process.

(Le Génie Civil, vol. viii., 1891, p. 430.)

The first operation in this method of producing oxygen consists in forming a combination of peroxide of lead and lime, called by the inventor, Mr. George Kassner, plumbate of lime, or calcium ortho-plumbate, from a mixture of litharge and calcium carbonate, which is heated to bright redness in a free current of air for ten minutes, the proportions of the two substances being indicated by the following equation—

$$Pb\,O + 2\,Ca\,C\,O_3 + O = Ca_2\,Pb\,O_4 + 2\,C\,O_2.$$

Carbonic acid is expelled, and the plumbate, whose composition may also be given as $2\,Ca\,O\,Pb\,O_2$, is obtained in porous or

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spongy masses giving a large surface for the absorption of air or gases.

2. The plumbate, when formed, is allowed to cool down to a low red heat, and is then subjected to the action of a current of carbonic acid. This inverts the former action. Carbonate of lime is reproduced, with the reduction of the peroxide of lead to monoxide, by the expulsion of one molecule of oxygen. Thus—

$$Ca_2 Pb O_4 + 2 C O_2 = O + 2 Ca C O_3 + Pb O.$$

The oxygen is either collected in a gas-holder, or may be led directly to the furnace, or wherever it may be required for use. It is found to be perfectly free from carbonic acid if the bed of plumbate has a sufficiently large absorbing surface.

3. The product of the preceding operation, a mixture of carbonate of lime and protoxide of lead, is revived, or rendered caustic, by passing steam over it at a bright red heat, which removes the carbonic acid. The latter gas is led into a gas-holder, and is stored for further use, so that there is no loss in the process. The steam simply acts as a carrier, and suffers no chemical change in the reaction, which is

$$2 Ca C O_3 + Pb O + \text{steam} = 2 Ca O + Pb O + 2 C O_2 + \text{steam}.$$

The decomposition of the carbonate is effected more rapidly and perfectly by this method than is the case with limestone burnt in kilns, owing to the ready permeability of the mass, which, as previously stated, is extremely porous.

4. The mixture of lime and lead oxide remaining after the expulsion of the carbonic acid, is peroxidized by passing air over it, when it is readily transformed into plumbate of calcium without increase of temperature, and is ready for further use.

$$2 Ca O + Pb O + O = Ca_2 Pb O_4.$$

The time required to perform each series of operations is about fifteen minutes. As compared with Brin's method of obtaining oxygen from the air by means of peroxide of calcium, the following advantages are claimed for the Kassner process:—

1. Smaller cost, as plumbate of lime can be produced for one-third of the price of peroxide of barium.

2. Larger yield. The peroxide of lead is completely decomposed at each operation, and yields its full amount, one molecule of disposable oxygen, while with barium peroxide only about 8 per cent.[1] of the disposable molecule can be obtained at each turn under the most advantageous conditions of working.

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[1] The comparative proportions of disposable oxygen appear to be—

a. With calcium plumbate 2 Ca O. Pb O + O 16 parts in 351, or 4·54 per cent.
b. „ barium peroxide Ba O + O 16 parts in 169, or 10·56 „

Eight per cent. of the latter quantity obtained at each operation is 0·84, or between five and six times as much oxygen is obtained from an equal weight of materials in the first as in the second process.

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3. Water, vapour, and carbonic acid have no injurious effect upon the plumbate, while, on the other hand, the air must be carefully freed from these substances before it can be allowed to act upon barium oxide.

4. The operations of forming and decomposing the plumbate can be effected in large furnaces, either blast or reverberatory, without mechanical appliances; and the ordinary process of their barium peroxide, on the other hand, must be treated in retorts containing only small charges, and an expensive exhausting and compressing plant is essential to the operation.

H. B.

New Electrolytic Method of Determining Metals.

By Edgar F. Smith.

(The Journal of the Franklin Institute, April, 1891, p. 296.)

The Author has investigated new methods of determining rhodium mercury, and gold by electrolytic separation in continuation of former researches upon the metals of the platinum group; the results are given briefly as follows:—

Rhodium.—From previous experience in the electrolysis of metallic solutions containing alkaline phosphates and free phosphoric acid, the Author was induced to try rhodium under similar conditions. A solution of sodium rhodium chloride $Na_6\ Rh_2\ Cl_3 + 24\ H_2O$, containing 0·0980 grain of rhodium in 10 cubic centimetres, was mixed with three times its volume of sodium phosphate solution, of specific gravity 1·0358, 0·3 of one of phosphoric acid, of specific gravity 1·347, and water to dilute it to eighteen times the original volume, and subjected to the action of a current capable of giving 1·8 cubic centimetre of mixed oxygen and hydrogen gases per minute. In seven hours the deposition was finished at the ordinary temperature of the air, the liquid first changing to a deep purple tint, but subsequently becoming lighter and finally colourless. The weight of the precipitated metal was 0·0982 gram, a result that accords so well with the theory as to prove the accuracy of the method.

In a second trial the electrolyte was diluted to 20 cubic centimetres, and the current gave 1·6 cubic centimetre of mixed gases per minute. The precipitation took place in copper-plated platinum dishes; the metallic rhodium was rather black in colour, very compact and perfectly adherent, and could be washed with hot water without any difficulty. The drying was done upon a warm iron plate.

Mercury.—Mercury sulphide dissolves readily in the fixed alkaline sulphides, and when in solution may be perfectly separated by electrolysis, which procedure affords a very accurate and clean

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method of estimating this metal. The solvent employed is a solution of sodium sulphide such as had been previously employed by the Author in the determination of gold; its specific gravity was 1·19.

Solutions of mercuric chloride, containing a known amount of metal, were first tried, the conditions of the experiments and the results being given in the following Table:—

Mercury Present.	Sodium Sulphide Solution.	Total Dilution.	Current O.H. Gas per Minute.	Mercury per Gram.
Gramme.	Cubic Centimetre.	Cubic Centimetre.	Cubic Centimetre.	
0·1903	20	125	1·0	0·1902
0·1903	20	125	1·0	0·1905
0·1903	20	125	1·0	0·1907
0·1903	20	130	1·2	0·1910
0·1903	30	130	1·2	0·1900

The precipitation was extended through the night. The mercury deposited was grey in colour and very compact, a tendency to take the fluid form having been only once observed. It was washed with hot water and dried by holding the platinum dish in the palm of the hand and blowing gently upon the deposit.

When mercury and arsenic are both present in a sodium-sulphide solution, the current will throw down the former metal, leaving the arsenic untouched. In two experiments solutions containing 0·1903 grams of mercury, and an equal weight of arsenic, gave 0·1908, and 0·1894 gram of the former metal with a current gave 2 cubic centimetres of mixed gas per minute.

Tin and mercury may be separated under similar conditions. In one experiment the solution containing mercury 0·1903 gram, tin 0·1200 gram, and 30 cubic centimetres of sodium sulphide, was subjected to a current that gave 2 cubic centimetres of mixed gas per minute for a period of twelve hours, when a precipitate of mercury, weighing 0·1909 gram, was obtained. In all cases the filtrates from the deposits did not show even traces of mercury when examined.

Gold.—In addition to the electrolytic separation of gold from solution as double cyanide, or in the presence of sodium phosphate and phosphoric acid, the Author has proved that it can be determined in the same manner by the decomposition of sodium sulphaurate. The sodium sulphide solution used is of the specific gravity 1·180, and is prepared by saturating caustic soda liquor with sulphuretted hydrogen, concentrating the liquid rapidly to the crystallizing point, and allowing it to cool in well-corked bottles. The crystals separated were removed, recrystallized and dissolved to form the electrolytic bath.

10 cubic centimetres of the sulphide solution containing

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0·1446 gram of dissolved gold, and diluted with water to 100 cubic centimetres was subjected to a current giving 26 cubic centimetres of gas per minute for a period of twelve hours. The gold deposit corresponded to the exact theoretical weight, and a similar result was obtained in another experiment in five and a half hours. The deposition was made directly on platinum, and was removed by covering it with a dilute solution of potassium cyanide, and leaving it at rest for several hours. It may be more speedily removed by connecting the dish with the anode of a battery, and using a platinum-rod as a cathode. Platinum will not dissolve if a weak current is used.

By suitable modification of the method, especially in the direction of using more sodium sulphide and weaker currents, gold may be accurately and completely separated from solutions containing it in the presence of equal quantities of arsenic, molybdenum, tungsten, and probably vanadium, the action of the current being continued for twelve hours. No separation from tin is, however, possible, even under conditions exactly similar to those in which antimony is separated from tin by electrolysis.

H. B.

The Practical Aspects of Electric Welding.

By F. A. C. Perrine, D.Sc.

(The Electrical Engineer, New York, vol. xi., 1891, p. 600.)

This Paper, read before the American Institute of Electrical Engineers, contains a brief account of the various objects in which electric welding is now successfully employed. The first welder actually sold was to the Roeblings, and in two years it made three hundred and seventy thousand splices in telegraph wire. This machine has been replaced by one large and seven smaller welders capable of working up to half-inch copper (40,000 watts), and, during the year they have been set up, show an average of one thousand welds per day. It is used by Messrs. Seaward and Son for uniting Norway iron and Swedish steel for carriage work; by the Pope Manufacturing Company for bicycle tires, the welds being finished in dies at the same heat. The Trenton Iron Company are now using it for joining their locked-wire rope, making, in fact, a solid bar of it for about 2 inches at the weld. It is also used for "spinning-rings" and steel axles up to 1½ inch diameter, these standing the test of bending to 90° and back again. The heaviest work is probably being done at the Johnson Rail Company's Works, and the hardest steel worked is that of band saws, and by this method even broken teeth are being replaced. Pipe-welding and bending is also being practised by several manufacturers by these means, the burrs being beaten down by rapid hammering, pneumatically driven or otherwise

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In the Charlestown Navy Yard anchor chains up to 2 inches are being made, the links being in halves and the two sides welded at the same time and forged at the same heat, and electrically welded shells are manufactured to dimensions requiring a minimum amount of machining.

The electric welding process is rather a melting together of the surfaces in contact than an actual welding; hence, cast metals are not changed in their essential constitution at the point of junction, but rolled or drawn metal is practically reduced to its cast state, and therefore requires further treatment on the weld to bring it to a satisfactory condition. This is especially noticeable with heavy sections, and the gradual change of condition can be clearly perceived on both sides of the weld. Special additions are therefore provided for reheating joints in such metals and subjecting them to further hammering hot and in special cases also cold; but even this treatment still leaves much to be desired where great strength and pliability are required. This caution applies especially to copper and to the higher carbon steels; thus, by forcing the heat, however rapidly, "burnt" steel can be produced electrically, and points rather to a rearrangement of molecules being the cause than any action of carbonization, especially as the metal can be restored by careful forging.

J. F.

The Direct Conversion of Heat into Electricity.

By R. J. GÜLCHER.

(Sitzungsberichte der Akademie der Wissenschaften, Berlin, vol. xix., 1891, p. 98.)

That electric currents can be developed by the direct application of heat to the junction of two different metals, which is the fundamental principle of the thermopile, was discovered by Seebeck in the year 1823. As regards the theory of the subject, Clausius suggested in 1880 that "by the molecular motion, which is termed heat, electricity is driven from the one material to the other;" and Kohlrausch's theory of 1875 is somewhat similar in assuming that the electric current is in some way connected with the flow of heat, and *vice versâ*. The discoveries of later years, culminating in the researches of Hertz, prove, however, that the electric current is merely the result of a certain vibratory motion of the luminiferous ether, and therefore, in accordance with the principles of the conservation of energy, a certain definite quantity of heat can be converted into a certain definite quantity of electricity without either loss or gain of energy, and it is this meaning that is given to the subject of this Paper, conversion by a dynamo machine being termed "indirect."

Proceeding then to calculate the absolute efficiency of the ordinary means of producing the electric current by a steam-driven dynamo, the electrical energy developed is shown to be

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only 6·4 per cent. of the energy existing in the coal burnt in the boiler; but even this low efficiency is eighteen times greater than the direct conversion of heat into electricity as furnished by a Noë and Clamond thermo-battery, where the efficiency works out at only 0·35 per cent. of the mechanical equivalent of the gas burnt. If the high efficiency of the dynamo and steam-engine in themselves, as manufactured at the present day, be considered, it is clear that not much greater results can be expected in that direction, and the Author has for some years been experimenting in other directions, therefore, for the direct conversion of heat into electricity.

The principal idea acted on at first was the heating of a certain metallic salt in a platinum crucible, which should form the positive pole of the element, and a carbon rod immersed in the molten substance, the negative pole; this substance would part with its oxygen to the carbon, and then be re-oxidized by contact with the air; and with this form of apparatus, a mixture of caustic soda and carbonate gave an electromotive force varying between 0·475 and 0·4 volt, the "sodium blast" generated at the carbon point burning at the surface with its characteristic yellow flame, accompanied with slight explosions. For the similar potash salts the electromotive force was between 0·4 and 0·31 volt, the flame being violet and the burning more violent, and forming a small display of fireworks. The adoption of lead oxide resulted in a momentarily high electromotive force, and then a sudden collapse of the platinum crucible, owing to the metallic lead reduced falling to the bottom and eating through the platinum. The Author was surprised also to find that at the junction of the platinum connection-wire the crucible was also severely pitted, as the current had never been short-circuited, and he has no valid explanation to offer therefor.

After these experiments, the results of which did not promise any simple solution of the problem, the Author set himself to improve, if possible, the thermo-battery, and for which purpose attention was directed to the following particulars:—

1. The adoption of durable materials.
2. That the electromotive force and specific conductance should be as high as possible.
3. Improvements in the form of the element.
4. Improvements in the application of the heat, *i.e.*, a higher efficiency in the production of the heat itself.

Subsulphide of copper, in spite of its high electromotive force, gave, on account of its high specific resistance, a weaker current than materials which gave only half its electromotive force, and it was also found that, by a species of dry electrolysis, granules of metallic copper were formed throughout the body of the material, and its use was therefore discarded. A form of battery is described, and which was exhibited at the meeting, consisting of tubes of nickel and a special antimonial alloy, which was found to be very durable; this consisted of fifty elements in series united

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in one casing, and gave an electromotive force of 3·5 volts, and an internal resistance, when hot, of 0·4 ohm, with a consumption of 7¼ cubic feet of gas per hour, and the absolute efficiency is 1·08 per cent., or three times that of the existing thermo-batteries. Such a battery is almost exactly equivalent to two Bunsen elements, and though it is far below the dynamo in efficiency, still it may be suitable for various small installations and for experimental work, owing to complete absence of polarization, as the electromotive force does not fall on short circuit. The durability is enhanced by a regulator applied to the gas-supply to prevent any accidental overheating.

The Author concludes by stating that he hopes to exhibit at the Frankfort Exhibition two cells which are the outcome of still later researches, and in which the efficiency has been raised to over 5 per cent., and thus almost capable of competing with the dynamo. The description of the construction is withheld; but it is stated that one form is capable of continuously furnishing current for eight 16 candle-power lamps at a consumption of 4·5 lbs. of coke per hour. This success the Author hopes still further to advance, and thereby exceed the efficiency of the dynamo system as a converter of heat into electrical energy.

F. J.

A Charge-Indicator for Accumulators. By E. HOSPITALIER.

(Le Génie Civil, vol. xix., 1891, p. 29. 1 Fig.)

The Author states that, considered as a reservoir, the secondary battery labours under the disadvantage that it has been hitherto impossible to ascertain readily its precise condition as to charge. Mr. G. Roux, head of the electrical laboratory at the École de Physique in Paris, has produced an instrument which entirely obviates this difficulty, and has given great satisfaction to the Author, who has used it for six months.

All instruments, except the differential counters, which have as yet been used for the purpose of ascertaining the state of charge of the cells, have depended upon the changes in density of the electrolyte. The density of the electrolyte is greatest when the cells are fully charged, and is least when they are completely discharged; between these two limits and for the ordinary changes in temperature the density varies proportionately to the quantity of electricity stored up.

Several densimeters have been brought out, but all give readings in absolute densities and not in the relative values of the variations in density between the two extremes, which is what is required. The chemical reactions also produce stratification of the electrolyte, and it is difficult with the ordinary instruments to obtain the mean density with precision.

Mr. G. Roux has got over these difficulties, and in his apparatus

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uses a densimeter of constant volume as an indicator. This consists of a flattened glass tube of a length about equal to the depth of the electrolyte. The thrust upon the tube is therefore the product of the specific weight into the volume of the tube, and this thrust is a measure of the mean density. The tube is weighted so that the resultant force acts downwards. It is hung by a platinum wire of about 0·0004 inch diameter from the end of a short lever, which is horizontal when the cell is fully charged, the lever is fixed upon a spindle, which carries a screwed rod at an angle of 45° to the lever, and upon it a small brass counterpoise can be moved. At right angles to the lever is fixed a long balanced pointer, which travels over a scale divided into one hundred equal parts, and of a length equal to the half chord of an arc of 90° struck by the pointer. A counterpoise on the continuation of the small lever serves for the original adjustment. When the cell is completely discharged the pointer should be at zero, and consequently make an angle of 45° with the vertical. It is brought to this position by adjusting a large weight, and when the cell is fully charged it is brought to 100 by moving a second weight.

Theory and experience show that under these conditions the pointer once regulated will indicate by its position upon the scale the percentage charge of the cell; also, if the plates were not fully formed to start with, the pointer will pass the 100, and thus the rise in capacity will be seen. One instrument is enough for a whole battery, but it is better to use two placed at hazard in connection with different cells. An alarm can readily be connected with the apparatus.

E. R. D.

Siemens Dynamo with Internal Field-Magnets. By F. Drouin.

(L'Electricien, 1891, p. 33.)

The Central Station in the Rue des Dames at Paris has been equipped with 500-HP. Corliss engines, and direct coupled dynamos of the type introduced by Messrs. Siemens and Halske in the Berlin stations. The field-magnet system is of star shape, and surrounded by the armature, which is of the Gramme type, but with the active part of the winding on the inner circumference. The following figures are given by the Author as referring to a dynamo for an output of 800 amperes at 200 volts. The machine has six poles.

Revolutions per minute	250
Linear speed of active conductors per minute	4,350 feet.
Total number of turns on armature . . .	714
Useful length of conductor per turn . . .	11 in.
Sectional area of armature core	42·5 square inch.
„ „ magnet core	140 „

The exciting current required is 25 amperes.

G. K.

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The Siemens and Halske Safety-Clutch. By E. Richter.

(Elektrotechnische Zeitschrift, vol. xvi., 1891, p. 49.)

The Author describes a new kind of magnetic friction-clutch for use in works where power is distributed by means of shafting and belts. The apparatus consists of two electro-magnets of annular form arranged on either side of the pulley which gives off power. The annular polar faces of the magnets are turned slightly conical, to correspond with the conical shape of the inner pulley rim, and one magnet is keyed to the shaft and revolves with it, whilst the other is firmly fixed to the bearing. Ordinarily the fixed electro-magnet is inert, and current is sent through the electro-magnet which is keyed to the shaft. The pulley is then strongly attracted on to it, and sufficient friction is caused to transmit the power. In case of an accident, when it is desired to stop the pulley as quickly as possible, the current in the revolving magnet is interrupted, and a current is sent through the fixed magnet, which in its turn attracts the pulley and acts as a brake. By these means not only is the power cut off instantaneously, but a very efficient brake is applied at the same time, thus stopping the machinery very quickly. The shunting of the current from the revolving to the fixed electro-magnet is effected automatically by a switch, which is controlled by a small relay magnet. The switch, in passing from one position to the other (impelled by a weight which the relay magnet has released), reverses for a moment the current through the revolving electro-magnet, thus ensuring the immediate release of the clutch, which might otherwise be delayed by residual magnetism. The relay magnet is controlled by push buttons placed at convenient positions throughout the works. The Author states that the electric energy required for keeping the clutch in gear is only 1 per cent. of the total power transmitted. The system is in use at the works of Messrs. Siemens and Halske, Berlin.

G. K.

Apparatus for Telephone-Exchanges. By G. de la Touanne.

(Annales Télégraphiques, vol. xviii., 1891, p. 121. 16 Figs.)

In the old method of switching, it is found that in an exchange of 1,000 subscribers, divided into ten groups, 72 per cent. of the conversations require the intervention of more than one operator, and in one of twice that number, divided into twenty groups, the percentage rises to 85. In order to obviate this defect, the multiple board, which brings all the lines within the reach of every operator, has been devised. The two-cord multiple board for earth return lines, and the modification necessary for those with

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metallic return, are described in considerable detail, the desirability of dividing the coils of the transmitter and receiver being pointed out. The Author then proceeds to describe a method devised by himself in 1887, but which has not been yet put to the test of practice, for ascertaining whether a line is engaged on a return circuit multiple board. It necessitates the subscriber keeping his receiver off the hook as long as he requires the line, and the fact of a line being engaged is evidenced by the ring-off indicator falling when the operator tries the line.

The following figures are given as showing the performance of the boards. At New Orleans four observations showed respectively 179, 217, 241 and 212 connections per operator per hour, while at Montreal 867, 985, 1,272 and 1,327 connections per operator per day were noted. At Nashville in five minutes 25 connections were actually made, and 30 were considered practicable. In order to still further accelerate the service, the single-cord multiple has been brought out. In this the time, amounting to three or four seconds, required to put the first plug into the jack, and to put down the trigger, is saved; but each line has to be provided with a separate cord. The details of this board are then fully described both for earth lines and those with a metallic return.

The Author proceeds to compare single- and double-cord boards, and arrives at the conclusion that the saving in time effected, namely, two or three seconds at making a connection, and one or two seconds at cutting off, only compensates for the greatly increased complication in exceptional cases, and even in these the advantage can only be felt with highly trained operators, since a few seconds are of relatively little importance if the operators are slow.

The actual form of the boards is next described, and a discussion of the best arrangement entered into. This is shown to depend on the number of subscribers, and the mean number of calls per subscriber, and attention is drawn to the importance of distributing the subscribers so as to equalize the work. As to the choice of the unit of the exchange, *i.e.*, the number of home sections on each board, it is shown that this is governed by two distinct considerations: (1) the necessity for finding space for the indicators, and for the home-section jacks being near the operator; (2) the fact that all the other jacks must be within his reach. The Author recommends making the unit as large as possible, since this diminishes the first cost and space required, improves the speaking by shortening the cable and lessening the number of contacts, and allows of better superintendence. He considers 10,000 jacks, exclusive of the home-sections, as the limit, and when this is exceeded it becomes necessary to have separate exchanges connected by trunks: (1) In the case of two exchanges, he advocates giving half these trunks to one and half to the other, the incoming lines only being furnished with indicators, while the outgoing are divided up among the boards in the exchange and are not multiple; (2) In the case of one main exchange with several branches, the

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outgoing lines are to be multiple on several neighbouring sections, so that a sudden rush of messages for any one exchange may be provided for. The Author then takes as an example the re-organization of the Paris system, and works out the best arrangement.

The Author concludes by advocating the erection of a small switch board to which a line from each operator's instrument is brought, so that the superintendent of the exchange can listen to what each one is saying, and, if necessary, speak to him.

C. H. W.

The System of Electric-wiring of the Interior-Conduit and Insulation Company. By E. H. JOHNSON.

(The Journal of the Franklin Institute, March, 1891, p. 161. 7 Figures.)

The system of the Interior-Conduit and Insulation Company was submitted for examination to a sub-committee of the Committee on Science and the Arts, constituted by the Franklin Institute. They report that the system is the subject of a number of letters patent, and that its purpose is to provide a means for running electric wires in and through buildings and underground, and that inasmuch as it differs essentially from the usual system of running such wires, it may be said to be a new departure rather than an improvement upon any existing system. It consists of a system of continuous tubes of insulating material, which are placed throughout the building, and into which the wires are afterwards drawn. The wires are thereby insulated electrically from the materials of the building, such as plaster, wood, pipes, &c., and the woodwork is also protected from being ignited by the accidental heating or short-circuiting of the wires themselves, thus protecting the building against liability to fires arising from such accidents. The tubes are made of paper or similar material treated and soaked in a bath of bituminous compounds at 460° Fahrenheit. They are made in sizes ranging from ¼ inch to 1½ inch diameter inside. They are hard, strong, and tough, and are made fire-proof, when necessary, by a coating of fire-proof paint on the outside, which prevents them from being ignited by flames from the outside, and also from acting as carriers for the flames; they cannot be ignited from the inside for want of sufficient air to support combustion; they are, therefore, in this sense, fire-proof, although made of inflammable material. It is claimed that they are water-proof, except where they have been cut, as at joints; they are secured to the walls of the building by a simple brass clip.

At corners or bends the tubes are connected with butt-joints to knee-pieces, the joints being enclosed in a sleeve. The centre of distribution in a building is chosen so that it is within about 35 feet

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of the outlets, so as to facilitate "drawing-in" of the wires. In underground work, a number of the tubes are enclosed in an iron pipe or cast-iron casing filled with an insulating compound. The wires are afterwards drawn into the tubes by means of a "pilot" line. Where the number of bends exceed five, junction-boxes are used. For large mains, a separate tube is used for the positive and negative leads, but for smaller branches the two wires run in the same tubes.

The wires have merely a light textile insulation, instead of the usual expensive fire- and waterproof covering. A series of experiments was shown to the Committee; a leak was forced between two wires run as usual on a wooden moulding 2½ inches apart, the moulding being moistened with a solution of soda. The leakage was too small to actuate the safety-fuzes, but was large enough to char and set fire to the wood. The wires were then placed close together as in the system of tubes, and the leak was produced as before, the leakage was then so great that the safety-fuzes acted immediately, before any charring or ignition of the wood could take place.

Further experiments were then made, the result of which was that the Committee gave it as their opinion that the invention was an improvement of great value, and recommended the award of the John-Scott-Legacy Medal and Premium to the company. The report was adopted, and the inventor, Mr. Johnson, then proceeded to give details of the application of the method to various purposes; the object being to supplant the former practice of attaching the insulation to the wire itself, and substitute a system of insulated channels into which the wires might be drawn. The system appears to have attracted the opposition of various interests in America, and the Author states that persons interested in certain rubber insulation, undertook to prove that the tube itself would burn by the external application of heat. This has been got over by coating the tubes with fireproof paint. It was alleged that the tubes disintegrated in time, in the presence of moisture, and also would do the same in cement. The Author states that both these difficulties have now been surmounted. He then goes on to describe the underground conduit system, which consists of a bundle of the paper tubes collected into a cast-iron pipe; the whole is then immersed in a bath of special insulating compounds maintained at a high temperature; when withdrawn, only that portion of the compound which has entered the tubes is allowed to escape, the remainder solidifying so that a solid mass is obtained with clear ways through it. These pipes are made in 10-foot lengths. The junction between each pair of pipes is formed by using tubes of a slightly smaller external diameter than the internal diameter of the tubes already in position, and the latter are inserted into the former so as to break joint, each joint of the smaller internal tubes occurring midway between the ends of the larger tubes; the ends of the external cast-iron pipes are then filled in with the insulating

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compound. Junction-boxes are employed as with other systems, and the branch mains are made in a similar way to those used for the main leads.

E. R. D.

The Ducretet Signal Switch-Board. By Henri Mamy.

(Le Génie Civil, vol. xvii., 1891, p. 316. 6 Figs.)

The Author states that the Ducretet combination-switch is that most frequently employed at present at sea for signalling by means of glow-lamps. It enables lamps to be lighted at a distance, whether they are placed upon the masts of a vessel, or upon land; also by this means different groups of lamps can be used, and thus a larger number of signals can be obtained. In the illustrations given, each group is composed of four glow-lamps; it is therefore possible to obtain fifteen different combinations by lighting one, two, three, or four lamps together. The switch-box is provided with a resistance-coil for each lamp, and this is switched into the circuit when no current is flowing to the lamp. Thus a constant total resistance is always maintained. The use of resistance-coils may, however, be avoided by the employment of a compound-wound dynamo. The signal switch-board consists of a case, inside which are placed a series of metal plates, one above the other, and corresponding in number to the number of lamps used for signalling purposes; each plate is insulated from the rest, and all are solidly attached to the slate top of the case. Each plate is connected directly to one of the lamps, and is provided with holes into which a contact plug can enter. The plug, which is made of metal, is cut in such a way that parts stand out from it in the form of springs, and ensure perfect contact between the plug and the plates, when the former is placed in position. The plates which are connected directly to the lamps, those connected with the resistance-coils, and the common plate to which one pole of the main leads is attached, are all provided with holes carefully bored and ground to a standard size where they are intended to fit the plug, and drilled with larger holes in the cases where no contact is intended to be made. The face of the instrument is marked with numbers referring to the special signal given when a plug is placed in any given hole. A switch is provided upon the same base-plate, which enables a second group of lamps to be used, in order to increase the possible number of signals, and another group is shown upon the mast below the first group. In order to give a signal, it is merely necessary to push the plug into the proper hole, and to withdraw it quickly to avoid sparking. The plugs are made of hard unoxidizable metal nickel-plated, the resistance coils are of German silver wound upon bobbins of incombustible material, and each coil is separately insulated with paper or asbestos.

E. R. D.

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The Electric Cables through the Gotthard Tunnel.

By — VON BAECHTOLD.

(Elektrotechnische Zeitschrift, vol. xvi., 1891, p. 85.)

The two cables laid through the Gotthard tunnel during the winter of 1881 to 1882 have been found insufficient for the increased traffic, and recently there have been laid two additional cables for the telephone service, one containing three separate conductors and the other two conductors arranged concentrically. The experience gained with the old cables (one a seven conductor telegraph and the other a single conductor signal cable) has not been quite satisfactory. These cables were laid in an iron trough fixed on one side of the tunnel, and it was found that the water which accumulates in the trough where it sags between the supports had an injurious effect on the insulation. To determine the nature of this effect one hundred and fifty samples of the water were analysed, and in many cases found to contain sulphuretted hydrogen and sulphates. Moreover, it was found that owing to the slower combustion in the air of the tunnel the smoke from the locomotives contains considerable quantities of ammonia and sulphurous acid, which, together with the carbonic acid, are absorbed by the water. It was therefore determined to abandon the previous method of laying the cables into a trough and to lay them directly in the ground. The old cables have also been relaid in this manner. A trench about 2 feet in depth was dug and filled, first, with 2½ inches of gravel, then 2½ inches of sand. Upon this were laid the four cables, and covered with 9 inches of sand, covered by granite flags, and the rest made up with ballast. The Author gives full details of the construction and electrical data of the cables and of the work in laying, which was complicated by the necessity of crossing over from one side to the other in the middle of the tunnel to avoid certain springs. This work of crossing over necessitated the frequent taking up and relaying of rails in the short interval between two succeeding trains.

G. K.

The Central Electric-Light Station at Hanover.

By W. KOHLRAUSCH.

(Elektrotechnische Zeitschrift, vol. xvi., 1891, p. 201.)

For some years past, small lighting-stations have been in use in Hanover, supplying blocks of houses with glow- and arc-lamps, the former on the alternating-current system. Eventually the town council decided to erect a large central station to supersede the various small undertakings, and tenders were invited in

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November, 1889. The work was entrusted to Messrs. Schuckert and Co., of Nuremberg, and has now been completed. The building has a frontage of 115 feet, and is 75 feet deep. It is divided transversely into three spaces for boilers, steam dynamos, and batteries respectively. There are at present installed three Steinmüller water-tube boilers, each of 2,000 square feet heating-surface, intended to evaporate from 2·25 to 3·40 lbs. of water per square foot of heating-surface, and room is left for two additional boilers. The chimney, which also serves to ventilate the battery-room, is 165 feet high, and 5 feet 6 inches internal diameter at the top. The two engines now in place are inverted triple-expansion condensing-engines, by Schichau, and are intended each to develop normally 300 HP. at 115 revolutions; but can be forced up to 400 HP. The cylinders are 16½, 27, and 41 inches diameter; stroke, 19·6 inches. The guaranteed steam-consumption is 13 lbs. of steam at 150 lbs. pressure per HP.-hour if condensing. The dynamos, which are of the Schuckert type, are direct-coupled, and have been designed for an output of 275 kilowatts, at either 320 volts, or 1,100 amperes. The armature is 10 feet in diameter, and the commutator is 6 feet 6 inches in diameter. The field contains 16 poles, and the current is collected by eight sets of brushes.

In the battery-room there is accommodation for four batteries, but two only are at present installed, each consisting of 136 Tudor cells, having a capacity of 1,320 ampere-hours, and a discharge rate of 396 amperes.

The station is designed on the three-wire system, with independent regulation of pressure in each feeder. The most distant lamp is 880 yards from the station. The mains constituting the network are lead-covered and iron-armoured cables, placed into the ground without further protection.

The feeders are lead-covered cables placed in U-shaped iron troughs. The total length of a single cable is about 50 miles, and three hundred and thirty customers are now connected, representing a total of 8,000 lamps wired. The mains have, however, been designed for the supply of 25,000 lamps. The charge for current is on the basis of 8½*d.* per unit; but discounts, ranging from 5 to 25 per cent., are allowed for high lamp-hours. For motive-power purposes, current is sold at 2½*d.* per HP. hour.

G. K.

The Municipal Electric-Lighting Station at Paris. By F. Meyer.

(Annales des Ponts et Chaussées, vol. xii., 1890, p. 813.)

In March, 1888, the Paris town council voted £40,000 for the establishment of an electric-light station, to be erected at the public market, and to serve for the illumination of the market, and neighbouring district. The total power of the station was to

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be between 800 and 900 HP., obtained by the employment of six groups of engines and dynamos of about 140 HP. each, of which number not more than four should work simultaneously, leaving two in reserve. A mixed system of supply has been adopted, namely, low-pressure continuous current for the market and the immediate neighbourhood, and high-pressure alternating current for the more distant streets and the supply of private customers. The total floor-space occupied by boilers and machinery is about 7,000 square feet. There are six Belleville water-tube boilers, each having 880 square feet of heating surface, and 33 square feet of grate surface. The total evaporative capacity of the boilers has been fixed at 10 tons of steam of fifteen atmospheres pressure per hour, or about 4¼ lbs. of steam per hour per square foot of heating surface. The chimney, which has been designed with a view to future extension for double this boiler-power, is 130 feet high, and 6 feet 3 inches diameter at the top. Two types of engines are used; vertical triple-expansion condensing-engines, by Messrs. Weyher and Richemond, and horizontal condensing-engines, with improved Corliss gear, by Messrs. Lecouteux and Garnier. The former drive by belt, three pairs of Edison low-pressure dynamos; and the latter by ropes, three Ferranti alternators. The Author gives full particulars as to construction and winding of these machines.

The low-pressure distribution is on the three-wire system, a balancing wire being used in the feeders as well as in the mains, and the regulation of pressure being effected by rheostats. The high-pressure distribution is by means of transformers in the usual way. All mains are underground.

The Author gives detailed descriptions of the kind of cable used in the two services, the regulating instruments, lamps, and meters. The actual cost of the generating- and distributing-plant, is as follows:—

	£
Steam-boilers and accessories	3,120
Steam-engines and accessories	7,200
Dynamos and alternators	5,520
Switch-boards and instruments	480
Mains within the markets	2,200
Fittings and lamps in the markets	4,200
Outside mains; low pressure	5,400
„ „ high pressure	6,400
Builders' work and chimney	5,900
Stores	720
Water-supply	800
Laboratory	280
Transformers	1,240
Office expenses	180

Taking boilers, engines, and dynamos only, the Author finds that this part of the plant comes to £16 per HP.

G. K.

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The Electric Lighting of Railway Trains. By F. Uppenborn.

(Elektrotechnische Zeitschrift, 1891, vol. xvi., p. 253.)

The Author describes more particularly the Khotinsky system of train lighting, but prefaces the description by some general remarks on the lighting of railway carriages. On some lines in Germany candles and oil-lamps are still in use, but during the last twelve years Pintsch's oil-gas has been largely introduced on main-line trains. Although this method of illumination is a distinct advance over the older illuminants, it is not quite satisfactory. The light is unsteady, especially in stormy weather; there is frequently an unpleasant smell due to leakage, and there is also a serious element of danger, as is shown by the terrible accident at Wannsee in 1880, at which several persons were burnt to death by the escaping gas. In all these respects electric lighting is better, though it may be more costly. The average cost of lighting by oil-gas varies between 0·38 and 0·69 of a penny per lamp-hour. The Author points out that the cost of lighting is in any case so small in comparison with the other traffic expenses that it may be entirely neglected, and he thinks that hitherto too much weight has been given to the supposed greater costliness of electric light; moreover in some cases the cost is not greater, in proof of which he cites the example of train-lighting undertaken by a works in Cannstatt, where the cost was found to vary between 0·31 and 0·41 of a penny per lamp-hour.

In the Khotinsky system each coach is provided with two distinct storage-batteries, and the lamps are arrayed on two distinct circuits, so that in case of accident to one circuit, or during the changing of the batteries, no compartment shall be left entirely without light. The storage-cells, which have been specially constructed to stand rough handling and vibrations, have a capacity of 200 ampere-hours at 16 volts and 7 amperes. Each battery supplies current to four 8 candle-power lamps for the compartments, and one 5-candle-power lamp for the lavatory. The weight of a battery is 6 cwt. The batteries are placed in boxes one at each end of a coach under the floor, and special arrangements are made for rapidly replacing the exhausted batteries by others newly charged. The wiring is on the outside of the coach, and one lamp in each compartment is provided with a switch and the other with a resistance by which its light may be reduced to 2-candle-power at the pleasure of the passengers. This light is in use on the line, Fulda–Frankfort, and is being fitted on one of the express trains running between Berlin and Frankfort.

G. K.

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The Repair of Glow-Lamps. By J. A. MONTPELLIER.

(L'Electricien, 1891, p. 65.)

The Author describes the process invented and used by Mr. Pauthonnier for replacing the filament of glow-lamps when broken. A hole is made in the top of the bulb sufficiently large for the withdrawal of the old and the insertion of the new filament, but in detaching the old filament care is taken to leave about $\frac{1}{16}$ inch of it at each electrode to form a stem to which the new filament is welded by the electro-deposition of carbon. For this purpose the lamp is placed with the terminals downwards on contact-springs, and the bulb is filled with a liquid hydro-carbon. The new filament is then introduced by means of a special tool, and one end is brought into contact with one of the stumps of the old filament. Upon sending a current through the junction carbon is deposited, and the old and new filaments are welded together. The other end is then treated in the same manner, and the bulb is emptied and cleaned. The opening is then closed by blowing on a glass tube, after which the lamp is put on the pump and finished as if it were a new lamp. The pump employed is of a new pattern, capable of exhausting five lamps simultaneously, the time required being three-quarters of an hour. The Author considers the process specially valuable for "sunbeam lamps," either for the replacement of the filament, or merely for the cleaning of the bulb.

G. K.

Power-Transmission by Alternating-Currents.

By M. VON DOLIVO-DOBROWOLSKY.

(Elektrotechnische Zeitschrift, vol. xvi., 1891, p. 149.)

After giving a short historical sketch of the work done by Ferraris, Haselwander, Bradley, Tesla, Schallenberger and Wenström, the Author points out that the two-phase current applied to a physical annular field-magnet produces a revolving field which has not a constant strength as generally assumed, but that the strength varies by 40 per cent. This he considers a serious drawback to the employment of a two-phase current, since the pulsation in the strength of the field produces a brake-action which is directly opposed to the forward pull due to the rotation of the field, and he considers it absolutely essential to reduce the amplitude of the pulsations to a minimum. This is done by the employment of a

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three-phase current, in which case the pulsation is reduced to 15 per cent. By arranging the coils on the armature of the generator so as to have a phase-difference of 120° instead of 60°, and connecting all the inner ends of the coils, the transmission can be effected by the use of only three line wires joined to their outer ends; that is, the same number as required in the Ferraris-Tesla system, but the total weight of copper is less in the three-phase current. This method of connecting the armature coils the Author calls "open-coil connection," to distinguish it from the "closed-coil connection," when the three coils are joined so as to form a closed ring, the line wires being connected to the points of junction. The Author gives a number of diagrams in order to show these various methods of connection, pointing out that for successful working it is necessary that the three branches of the system should be equally loaded. Should this not be the case, then any attempt to equalise the load by choking-coils or similar devices would lead to complications and new difficulties which, in the Author's opinion, would outweigh any theoretical advantages of this system in which the line is directly connected to the coils. To overcome these difficulties, the Author discards direct connections, and places a transformer between the machine and the line wires. The machine is constructed to give six independent currents, which are used to produce a rotating field in a transformer of special construction, and the secondary coils of this transformer are grouped so as to produce the three-phase current. The interpolation of the transformer, although it might appear at first sight to be a very undesirable complication, is in reality an advantage, since the machine can be made for low voltage, and consequently mechanically strong, and of high efficiency. Moreover, for long-distance transmission at 10,000 volts or more, step-up and step-down transformers are in any case required.

The Author next compares the energy which can be transmitted with a given weight of copper in the line by means of the three-phase current and the ordinary alternating current. Calling e the potential difference between any two conductors, and J the current in any one conductor, the total energy is $1{\cdot}732\ Je$. To transmit the same amount of energy with a continuous or an ordinary alternating current flowing under the same potential difference would require the strength of the current to be $1{\cdot}732$ J. The cross section of each of the two wires in this case would therefore have to be $1{\cdot}732$ times that of each of the three wires when the transmission is effected by the three-phase current, showing a saving of from 13 to 14 per cent. in the weight of copper with the latter system.

Three types of motors are used. For very small sizes up to $\frac{1}{4}$ HP., the field is a kind of Gramme ring with internal teeth, between which are wound the exciting-coils. The armature is a solid iron cylinder, through which pass, near its circumference, stout copper bars, arranged parallel to the spindle, and with their

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ends connected by two copper rings. In larger motors the field consists of charcoal-iron disks, smooth on the inner circumference, and held together by stout copper bolts passing through insulated holes near the inner circumference. All the ends on one side are in metallic connection by means of a copper ring, whilst the other ends are joined to the secondary terminals of the step-down transformer. The armature is similar to that already described, except that instead of being made of solid iron the core is composed of disks. A third type of motor is more especially intended for use on town circuits, and in it the field is arranged to revolve within a fixed armature, being the converse of the first design.

The Author publishes the results of tests made with a 2-HP. motor of this construction, and gives curves of speed, current, power and efficiency. The motor is designed for a pressure of 70 volts, and a frequency of thirty-five complete cycles per second. It weighs 370 lbs., and is intended to run at about 2,000 revolutions per minute. At half-load the efficiency is 75 per cent., and at full load 80 per cent. The range of load over which the efficiency is high is shown by a curve to be considerable, and it is also shown that the motor may be overloaded to twice its normal load without damage. In conclusion, the Author states that there is only a small lag between electromotive force and current, making the ratio between apparent and true watts more nearly equal to unity than is the case with an ordinary alternating current. In the example given the apparent energy is 2,079, and the true energy 1,830 watts, giving a plant efficiency of 88 per cent.

G. K.

Electric Transmission of Power by Alternating Currents.

(The Electrical World, New York, vol. xvii., 1891, p. 223.)

In this article a description is given of a 100-HP. transmission-plant erected at Telluride, a small mining town in South Western Colorado. The mines are owned by the Gold King Milling and Mining Company, and are situated 11,000 feet above sea-level, and 3,000 feet above the San Miguel Valley. The gold ore being of low grade, and the supply of fuel becoming scarce, it was considered necessary for profitable working to discontinue the use of steam-power at the mills and substitute electrically transmitted power. In the valley a power station has been erected with an ultimate capacity of 800 HP., though only 100 HP. is taken up at present, by two 6-feet Pelton wheels coupled direct to Westinghouse alternators wound for 3,000 volts. The motor-station is 2½ miles from the generating-station, and the transmission of current is effected by bare copper wire, No. 3 B. and S. gauge, erected on poles. The loss is 5 per cent. Both the generating-

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and receiving-machines are ordinary alternators of the synchronizing type, and a 10-HP. Tesla two-wire motor of the revolving field type serves to start the motor, and bring it into step with the power current. After that the Tesla motor is cut out and the synchronizing-motor remains in step and delivers power.

G. K.

The Applications of Gutta-percha. By — LAGARDE.

(Annales Télégraphiques, vol. xviii., 1891, p. 5.)

Gutta-percha, as found and used, especially in the manufacture of submarine and subterranean cables, is a combination of several substances. The experiments made by the Author and detailed in this Paper were undertaken with the view of ascertaining the influence possessed by each of these substances on the insulating-power of the gutta-percha. The substance regarded as pure gutta-percha is accompanied by two resins—fluavile and albane, which exist in varying proportions in the commercial product. The more fibrous a gutta-percha is the better is its quality for most of the purposes for which it is used. Its specific gravity is greater than that of water, but apparently less on account of the air which is enclosed. Pure gutta-percha being insoluble in ether and alcohol, while the accompanying resins are soluble in these liquids, a complete separation of the resins can be effected by boiling the raw material in absolute alcohol. The albane being soluble in boiling alcohol only, advantage is taken of this property to separate it from the fluavile. The mineral constituents of gutta-percha being present in very small proportion—in no case above $\frac{1}{2}$ per cent.—were not specially considered in these experiments. As the result of a series of tests it was found that the greater the proportion of pure gutta-percha in a given sample, the less was its insulating power, and the Author therefore recommends that, in specifying the qualities to be possessed by cables insulated with gutta-percha, it is advisable to fix a maximum as well as a minimum of insulation.

Experiments were also made to ascertain the influence of the water contained in gutta-percha on its insulating-power. It was found that the power of insulation diminished in proportion to the percentage of water, all other conditions being similar.

Thin sheets of gutta-percha were exposed to air and water respectively for two months, after which time it was found that the proportion of resins had increased at the expense of the pure gutta-percha. When the material contained a large proportion of

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water in the first instance the change took place more rapidly, and for this reason the Author considers that the percentage of water in the gutta-percha insulation of cables should not exceed 5.

In order to test the influence of exposure to the air on the insulation of cables, a length of 1,000 metres (1,093 yards) was tested at intervals of one month, when the insulation was found to be better and the proportion of resins in the gutta-percha greater than at the date of manufacture. It is therefore important that cable-tests should be carried out at a definite interval from the date of manufacture.

As a result of his experiments, the Author recommends that, for telegraphic cables with gutta-percha dielectric, the proportion of resins contained in the material used should be specified, and that the proportion of mineral matter should not exceed ½ per cent., and of water 5 per cent. The insulating-power of the pure gutta-percha was found to be about three-quarters of that of the commercial substance before the separation of the resins.

W. F. R.

High-Speed Electric-Railway Work. By O. T. Crosby.

(The Electrical World, New York, vol. xvii., 1891, p. 207.)

This is a Paper read before the American Institute of Electrical Engineers in February 1891, and contains (*a*) an account of experiments made for the Electro-Automatic Railway Company of Baltimore, and (*b*) details of an experimental high-speed railway on a larger scale now about to be built. The first or historical part of the Paper goes back about four years, when Mr. D. G. Weems began to take up the question of a very high speed and entirely automatic service. To demonstrate the possibility of such a service, a circular track, 28 inches gauge, and nearly 2 miles in circumference, was laid at Laurel with 16-lb. rails. The locomotive was a steel box, 16 feet long, 24 inches high, and 30 inches wide, with pyramidal ends. Originally it had been designed with three axles, each to receive power from an electro-motor with armature keyed direct on the axle, but the centre motor was eventually taken away, as it was found that a higher speed could thus be obtained. The weight of the locomotive was about 3 tons. A second car was also made to be attached to the locomotive, the intervening space being flanged over to diminish air-resistance. Each motor was designed to develop 20 HP., and a speed of 250 miles per hour was contemplated. Actual experiment,

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however, showed that the speed had been over-estimated, and the best performance was only about 100 miles per hour. One of the greatest difficulties which became apparent during these experiments arose from the inefficient construction of the road, the rails being too light and badly laid, causing frequent derailments. The experiments were, however, useful in establishing certain data as to traction and air-resistance at high speeds. Based on these data the Author calculates the power required for the new experimental line to be built, and finds the following figures:

Speed in miles per hour	150	120
HP. required for locomotive alone	360	288
" " " and one loaded car . .	460	369
" " " " two loaded cars .	560	446
" " " " three loaded cars .	660	528

These figures refer to a level road of standard gauge, and with rails of from 65 to 90 lbs. The traction coefficient at 150 miles per hour has been taken at 25 lbs. per ton, and the air-resistance at 15 lbs. per square foot of cross-section if the ends are pyramidal. The locomotive is estimated to weigh 18 tons, and each loaded car 10 tons. The cross-section of all the rolling stock is to be 5 feet by 6 feet, that is, sufficient to accommodate passengers. Each locomotive will contain two motors, with their armatures keyed direct on the driving axles. Field to be of the Manchester type, armature Gramme wound for 1,500 volts, and 30 inches in diameter by 40 inches long. The cross-section of the armature core is 110 square inches net, and the total induction 22,000,000 C.G.S. units. The Author gives detail drawings of these machines, and enters at length into the leading features of a line 1,000 miles long. The Paper also contains estimates of working expenses and receipts to be expected from a line of this kind.

G. K.

Cable- and Electric Railways. By H. M. Kebby.

(Journal of the Association of Engineering Societies, Chicago, February, 1891, p. 79.)

This Paper, which was read before the Engineers' Club of St. Louis, discusses the question of the comparative construction and working of cable- and electric railways. For the purpose of comparison, Mr. Kebby assumes a road of 10 miles in length, single way, running thirty trains; and he bases his comparisons on results of roads constructed during the year 1890. A 78-lb. rail is in general use, and is assumed for both systems. The

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differences in first cost in favour of the two systems respectively are summarised as follows:—

DIFFERENCE IN FAVOUR OF CABLE ROAD.

	$		£
Paving	9,464	or	1,970
Wiring and poles	52,500	„	10,940
Motors and trucks	126,000	„	26,250
Machinery in power plant	25,000	„	5,210
Totals	212,964		44,370

DIFFERENCE IN FAVOUR OF ELECTRIC ROAD.

	$		£
Yokes	52,800	or	11,000
Concrete	40,000	„	8,330
Excavation	12,260	„	2,550
Carrying sheaves and manholes	13,600	„	2,830
Slot rails	49,280	„	10,260
Paving plates	26,400	„	5,500
Sewerage	2,500	„	520
Extra bolts	1,500	„	310
Large sheaves and pits	9,000	„	1,870
Cable	15,840	„	3,330
Extra labour	20,000	„	4,160
Grips	2,400	„	500
Totals	245,580		51,160

From these data it appears that there is a difference of only $32,616, or £6,790, or £679 per mile, in favour of the electric road.

With regard to the so-called dead weight of cable, sheaves, and winding machinery, kept in motion continuously, the weight of a 10-mile cable is 132,000 lbs., carried on sheaves with the best lubricated journals, against an excess of 6,000 lbs. for each motor car—or, for thirty motors, 180,000 lbs.—on the electric road, rolled over rails covered in a greater or less degree with dirt and mud from the street.

The working expenses for a cable-road 10 miles long, working thirty trains, amount to 2·441 cents, or 1·22*d.* per car-mile run. These comprise expenses of the power-house, repairs and renewal of grips, repairers' wages, lubricants for sheaves, renewals for sheaves and expenses of the road-bed, and renewal of cables. On the road in question there is a total curvature of 467½ degrees, and 20,000 lineal feet of gradients of from 1 to 3·6 per cent. The sheaves are lined with babbit-metal, for the sake of perfect noiselessness. With chilled cast-iron sheaves, the working-cost would be reduced by about 0·6 per cent.

Quoting Mr. G. W. Mansfield, the Author estimates that the cost of maintenance on electric roads—oilers, wipers, or cleaners, grease, repairs of electric apparatus on the cars, including the truck—amounts to about 3 cents, or 1½*d.* per car-mile. On small roads the cost is greater—perhaps 4 or 4½ cents, or 2*d.* to 2¼*d.*

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The average power-house expenses, according to Mr. Crosby, are 3·067 cents, or 1·533*d.* per car-mile, making a total of 6·067 cents, or 3·033*d.*

The indicator power required to move the cables and machinery alone was 139·95 HP. To pull cars and passengers in addition, a total of 287 indicator HP. was required, of which 48·76 per cent. was consumed for the cable and machinery alone.[1]

The Author estimates from what he can learn that the loss of power on an electric road would be, under average conditions, from 58 to 70 per cent.

Summing up, the Author concludes that for a line 5 miles long, double way, in a large town, $32,616, or £6,795 more would have to be invested for cable-power than for an electric road. But that if the business of the road would warrant the running of thirty trains per day, the cost on the cable system would amount to $53,457·9, or £11,137, against $132,867·3, or £27,680, on the electric system.

In discussion of the Paper, Mr. E. D. Meier gives working results of one cable railway, 9·64 miles long, and two electric railways, 9 miles and 12·22 miles long. The running-speeds were respectively 9·038, 7·5, and 9·522 miles per hour, and the cost for power was 5·06, 4·53, and 2·72 cents, or 2·53*d.*, 2·26*d.*, and 1·36*d.* per train-mile. The fact that many more trains were run per day on the third line above noted than on the others, may serve to explain the relatively low cost in that case.

D. K. C.

The Budapest Electric Tramways. By F. Uppenborn.

(Elektrotechnische Zeitschrift, vol. xvi., 1891, p. 173.)

Three electric tramways are now in use in Budapest, and three more are in construction. The first line was opened for traffic in July, 1889, and is 1½ mile long; the second, which is 2¼ miles long, was opened in September, 1889; and the third line was opened in March, 1890. These lines are worked by continuous currents at 300 volts through underground conductors supplied from a central station of 300 HP. total capacity. The rails are double, leaving a slot of 1·3 inch between them, which on one side extends into an underground culvert 11 inches wide by 13 inches deep. The rails over the culvert are supported by cast-iron chairs placed 4 feet apart, and these chairs also serve as supports for the insulators carrying the two bare copper conductors. The culvert is drained by sump holes connected with the town sewers. Each car is provided with a motor placed

[1] The power for the cable and machinery only is stated to be 47·65 per cent. in the original paper.—D. K. C.

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between and supported by the two axles so as to be entirely independent of the car-frame. Between the spindle of the motor and the car-axle there is a countershaft, and the gear is by link chains. The authorized speed varies between 11 miles per hour in the outskirts of the town, and 6 miles per hour in the central and more frequented parts. At crossings the speed is reduced to $3\frac{3}{4}$ miles per hour. The Author gives tables showing the traffic in each month on each of the three lines, from which it appears that the number of passengers per car-mile on the most frequented of these lines varies between 11·6 and 15·3. The number of car-miles run by each car in sixteen hours varies between 75 and 93. A total of nearly five millions of passengers had been carried by the three lines up to the end of 1890.

G. K.

A Photographic Study of the Electric Arc based upon Experiments made by Mr. J. C. McMynn. By Prof. E. L. Nichols.

(The Electrical Engineer, New York, vol. xi. 1891, p. 592.)

The humming of an alternate-current electric arc has been ascribed at various times to different parts of the circuit or mechanism of the arc, but that it is due to the periodic extinction of the arc at each reversal seems evident from inspection of the photographs reproduced in the Paper. These were taken on plates moved rapidly at right angles to the direction of the arc, and show in some cases alternations of completely dark and light spaces, and in others only partial extinction at the centre of the arc, so that a light band is produced with periodical dark spots. If the plate were moved parallel to the arc an oscillatory movement to right and left is revealed, and ascribed by the Author to the effect of the earth's magnetic field and direction of the current, because if the arc be viewed from the west the oscillations are not apparent. This vibratory effect could be largely increased by placing the arc in the field of an electro-magnet. The hissing of the continuous-current is evidently the result of a very rapid vibration of the flames, revealed by the fine striæ with which the negative of the photograph is marked. These flames are intermittent and irregular, whereas the arc itself is constant.

F. J.

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Giraud's Thermo-Electric Stove. By E. HOSPITALIER.

(Le Génie Civil, vol. xix., 1891, pp. 30 and 46. 2 Figs.)

The Author refers to the want of success which has attended the use of thermo-electric batteries as sources of energy, and to the large consumption of gas, which has been found necessary, so that only about 0·5 per cent. of the thermal energy is obtained in the outside circuit for lighting purposes. He believes, however, that the problem is entirely different where it is possible to use the combustion of the gas or coal for heating purposes, and the thermo-electro stove, brought out by Dr. Giraud, of Chantilly, fulfils the latter requirement. The stove resembles in outward appearance the ordinary stove used for heating purposes, but the products of combustion rise vertically in a cylindrical chamber and descend between this and a second envelope concentric with the chamber before passing to the chimney. This arrangement protects the metallic contacts from excessive heating, and equalizes the temperature to which they are exposed. The heated gases come into contact with a series of rectangular boxes of stamped iron plate forming a kind of cylindrical hive or chequer-work, in which are placed the thermo-electric elements. These elements to the number of about seven hundred are placed in the large pattern of stove in a series of twenty-five horizontal rings, and in a smaller type shown in the figures in a series of eighteen. The elements consist of couples of nickel or tinned iron, and an alloy mainly composed of zinc and antimony, to which other metals are added in small quantities, in order to increase the strength and retard fusion. The elements, which are set in cells in the stamped plate, are insulated by a coating of asbestos, and cooling is effected partly by the wing shape of the elements and partly by the circulation of air between them.

The whole of the seven hundred elements are joined in series, and give practically the same electromotive force whether nickel or tinned iron is employed. The electromotive force at full power is about 40 volts, and the current produced on short circuit is about 4 amperes. At its maximum useful power, which is the only point necessary to consider, as the consumption of combustible matter is independent of the energy of the battery, the useful output is 40 watts, equal to about 1 kilowatt-hour per day for continuous working. The consumption of coke to effect this result is about 61·6 lbs. per day, and with coke costing 27·5*d.* per cwt. (*sic*) the cost per kilowatt-hour would be 15*d.*, which is exactly the maximum price demanded by the central stations in Paris. As the output is too small to supply more than one lamp coupled direct, it is necessary to use accumulators, which raises the cost of the installation and reduces the quantity of electricity obtainable.

In reality the electricity is obtained more expensively than from the central stations; but it must be remembered that the heating of the rooms is also obtained. E. R. D.

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Some Possible Modifications in the Methods of Protecting Buildings from Lightning. By N. C. D. Hodges.

(Transactions of the American Institute of Electrical Engineers, vol. viii., 1891, p. 159.)

The Author, starting from what he confesses to be a wrong idea, but ultimately reverting to it by statistical confirmation, advocates the adoption of a fine copper ribbon in short lengths, say about 2 feet, fastened down the building and partially insulated at each junction so as to offer more resistance to the discharge, no special earth connection being provided. The object is to use up the energy of the electric discharge in dissipating the conductor, as the Author can find no record of a lightning stroke where any damage has been caused to a building between two planes enclosing the upper and lower ends of a wire thus dissipated.

F. J.

Note on an Underground Line laid in a Cement Conduit. By E. Brylinski.

(Annales Télégraphiques, vol. xviii., 1891, p. 163.)

The Author relates his experience of a line from Tarare to Roanne, a distance of 25¾ miles. It was constructed in 1885, and consists of three cables laid in a cement conduit. In 1890 it was examined, and three hundred and ninety-four faults removed. They were found to fall into two classes:—

(1) Those due to lightning discharges. These were shown either by a small round hole in the insulation, or else by a rent extending nearly round the wire; in either case the copper was blackened by oxidation near the hole, and when the discharge had been violent, bits of broken copper were found. When the insulation was otherwise good these faults were easily found and removed.

(2) The faults of the second type were quite different; long lengths of a mile or more were found to be rotten, the outer covering of yarn and prepared tape having completely disappeared. The trough contained an ill-smelling blackish liquid, and the gutta-percha on the wires was covered with yellowish-grey stains, apparently due to particles of cement torn off by the water which flows in the conduit and deposited on the insulation. This is proved by the top cable, which was not in the water, being little affected. The Author is of opinion that the mischief is started mechanically, and that a chemical action then sets in, rendering the gutta-percha spongy, and the insulation very low. These faults were most difficult to repair, working on one causing another to develop near it. After careful examination the Author was

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unable to find any relation between the faults and the surroundings of the line, though the composition of the cement varied from point to point, and this, apparently, had something to do with the action. A noteworthy fact is that the cables were unequally attacked.

C. H. W.

On the Determination of the Dielectric Constant of Glass for very Rapid Oscillations. By R. Blondlot.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxii., 1891, p. 1058.)

Professor J. Thomson has from his experiments concluded that for oscillations of the order of 25,000,000 per second the specific inductive capacity of glass is very nearly equal to the square of the refractive index, and is much less than for slower reversals. Mr. E. Lecher, on the other hand, arrives at the conclusion from his own experiments that this value actually increases for rapid oscillations, thus being diametrically opposed to the above confirmation of Clerk Maxwell's theory. The Author's experiments, however, give almost exactly the same value as Professor Thomson, and though this is somewhat larger than that demanded by the theory, it is at any rate much less than for slower oscillations. A condenser formed of two parallel plates can be discharged internally by two knobs, and its oscillatory frequency is of the order of 25,000,000 per second. On the opposite side of one plate, and therefore subject to the periodic magnetic field produced by the condenser discharge, are symmetrically placed two other plates, connected to which are the terminals of a spark micrometer. If the electrical fields of these two plates are equal, no spark will be visible at the micrometer, but if between one and the condenser-plate a sheet of glass be interposed the equilibrium will be disturbed, but can be re-instated by interposing a certain thickness of sulphur between the other and the condenser; and as sulphur is an almost perfect dielectric, the ratio of the two serves to determine the absolute value for the glass—$2 \cdot 8$ or $(1 \cdot 67)^2$—the index of refraction for this glass being $1 \cdot 51$.

F. J.

The Soldering of Glass and Porcelain Tubes to Metals. By — Cailletet.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1891, p. 165.)

This process consists in covering those parts of the glass or porcelain which are to be soldered with a layer of metallic platinum, on which is electro-deposited a coating of copper. The *modus*

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operandi, which is very simple, is to slightly heat the surfaces, and then paint them over with thoroughly neutral platinum chloride mixed with essential oil of camomile. The piece is then again slightly heated, until the fragrant white fumes are driven off; the temperature is next raised to a dull red, by which means the platinum is reduced, and forms a metallic film perfectly adhering to the glass. The work is then attached to the negative pole of a battery of convenient strength, and placed in a bath of copper sulphate. This deposits on the platinum a ring of copper which, if the operation is carefully performed, will be tough, and thoroughly adherent. In this condition the tube may be soldered by means of tin to iron, copper, bronze, platinum, or any other metal susceptible of soldering by tin. The solidity and strength of the joint are very great. The Author stated that a tube of his apparatus for the liquefaction of gases, of which the upper end was closed by a metal cock so attached, resisted pressures of more than 300 atmospheres.

Silverizing may be substituted for platinizing in this process, when the glass is painted with silver nitrate, the other operations remaining the same. The silver so applied unites well with the glass, but a considerable number of tests shows that in the majority of cases the use of platinum is preferable to that of silver.

F. G. D.

Cailletet's Cryogène. By MAX DE NANSOUTY.

(Le Génie Civil, vol. xix., 1891, p. 92. 1 Fig.)

This is a new apparatus, constructed by Mr. Ducretet from the designs of Mr. Cailletet, and intended to produce cold of 95° to 110° below zero Fahrenheit, by the expansion of liquid carbonic acid. The apparatus consists of two concentric vessels with a small annular space between them. A spiral coil is placed inside the inner vessel, and this is put in connection with a closed vessel containing liquefied carbonic acid. The apparatus is made of nickel-plated copper. The spiral coil is in connection at its lower end with the annular chamber, and is provided with a stop-cock at the top. When experiments are to be made the inner vessel is filled with alcohol, the stop-cock on the carbonic acid vessel is fully opened and the cock upon the spiral coil partially opened, the liquid carbonic acid passes slowly into the coil and takes the form of snow; it passes through the coil into the annular chamber, in which are placed pieces of sponge soaked in alcohol, which arrest all acid which has not become gaseous, and the gas itself passes out of the apparatus by a bent tube. The Author states that with about 5¼ pints of alcohol in the inner vessel, which acts as a bath in the experiments, and with a consumption of from 4·4 to 5·5 lbs. of liquid carbonic acid, a temperature of 95° below

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zero Fahrenheit can be obtained in a few minutes. When the circulation is stopped the apparatus cools very slowly, as it is surrounded with non-conducting coverings. In one test it was found that after nine hours the temperature of the alcohol had only risen from 95° to 7·5° below zero. By allowing a small quantity of carbonic acid to pass continuously a constant low temperature can be obtained.

E. R. D.

The Schiseophone. By Eugène Flachat.

(Le Génie Civil, vol. xix., 1891, p. 97. 5 Figs.)

Some interesting experiments have recently been made at Ermont, the depot for material of the Northern Railway of France, with the schiseophone, an instrument invented by Captain de Place, professor of fortification at the cavalry school of Saumur. The instrument enables interior flaws in metal to be detected, and the experiments were made upon rails. There is great difficulty in detecting internal flaws by the ordinary method of testing by blows, and this is especially the case with hardened metals. Captain de Place therefore uses a microphone fitted with a mechanical striker which enables a blow of known force to be given upon the surface of the metal to be tested, and the microphone is placed in circuit with a battery; the two ends of the circuit being brought to a fixed bobbin placed at zero upon a divided scale. Upon the same scale is placed a movable bobbin connected to a telephone. The bobbins and scale form the audiometer. When the mechanical striker is used upon sound parts, the metal will give out a tone which will cause the current from the battery to change in certain proportions. The movable bobbin will have currents induced in it which will depend upon its distance from the fixed bobbin, or upon the primary currents in the latter. Such a position of the two bobbins may then be obtained as will produce perfect silence in the telephone so long as sound parts of the metal are explored, but so soon as the striker acts upon a part which contains a hidden flaw, the chamber will by its resonance augment the sound, and this will be heard in the telephone. The instrument is contained in a case divided into four compartments. The first contains the audiometer, the second the telephone, the third the microphone and striker, and the fourth, six small sal-ammoniac cells provided with a special absorbent invented by Captain de Place. This substance he calls *mélasine*, and states that while acting as a superior absorbent it produces no internal resistance in the cell, prevents creeping of the electrolyte, and keeps the surface of the zinc clean and does not dry up. The contacts are formed in the box itself, and switches are provided which enable the elements to be changed every quarter of an hour to avoid polarization. After

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the experiments had been made the rails were broken, and flaws were found where they had been discovered by means of the instrument, although the audiometer and the rail under test were in different rooms separated by a wall.

It is more difficult to discover flaws in irregular shaped objects, but this is satisfactorily done. After some practice the operator can obtain good results, and it is preferable to place the movable bobbin at such a distance from the fixed bobbin that a slight sound is obtained even when perfect parts of the object are explored, and to allow the difference between the sounds to be judged of by the operator.

E. R. D.

A Baroscopic Thermometer.

(Le Génie Civil, vol. xviii., 1891, p. 308. 2 Figs.)

Until the present time thermometers, except those containing mercury or alcohol, have usually depended upon the deformation of a body from the expansion of its mass when subjected to heat. The Bréguet metallic thermometer is a type of this class, and all such instruments are liable to error, from the fact that after a certain period the expansive part, which constitutes the thermometer, suffers molecular changes from the constant movements to which it is subjected, and becomes useless as an exact measure of the temperature.

The object of such instruments is to obtain the movement of a needle upon a graduated scale, so that a reading may be taken at a distance. The Author states, that the present instrument has been produced by Mr. Debaecker, in order to avoid the necessity for obtaining the initial movement of the pointer from the deformation of a body, and to effect the same result by the force of gravity.

The instrument consists of a tube with a bulb at one end; both bulb and tube are filled with mercury, and the tube is placed in a horizontal position and supported upon a fulcrum close to the bulb; the other end of the tube is coiled upon itself in such a way that the coil forms part of a spherical surface, having the fulcrum as centre, in order to ensure the centre of gravity of the coil being always at a constant distance from the fulcrum. The bulb lies below a horizontal line passing through the centre of the tube, and the fulcrum consists of a knife-edge poised upon a hard steel surface. The extreme end of the tube is furnished with a pointer which travels over a scale formed as an arc of a circle, with the fulcrum as centre. The scale can be adjusted in height in order to obtain a reading at zero, when the arm of the balance is in equilibrium at zero temperature, or at any temperature which

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may be required; a small counterpoise is also used upon the tube in order to obtain the primary adjustment. The action of the instrument depends upon the fact that an increase of temperature causes the mercury to expand and pass from the bulb to the spiral coil, the long arm of the balance then falls until the equilibrium is obtained by the movement of the bulb upwards, which increases the distance of its centre of gravity from the fulcrum.

Instruments of similar construction have also been made by the inventor for closing electrical contacts at a certain given temperature.

E. R. D.

The Pressure-Gauge on the Eiffel Tower. By MAX DE NANSOUTY.

(Le Génie Civil, vol. xviii., 1891, p. 385. 1 Plate.)

A pressure-gauge 984·3 feet in height has been constructed upon the Eiffel Tower in Paris, by Messrs. Cailletet and G. Eiffel. The Author states that pressure-gauges open to the atmosphere are the only instruments by which the pressure of gases and liquids can be accurately measured, and Mr. Cailletet had previously constructed such a gauge upon a hillside, and afterwards another in an Artesian well at the Butte aux Cailles, which was 328 feet in height. Several other physicists have constructed similar instruments, but the practical difficulties in using apparatus fixed in such positions led to inaccurate results.

The Eiffel Tower offered exceptional advantages, as the whole length of the tube could be examined. The pressure of 400 atmospheres, which can be measured by such an instrument, is too great for a glass tube; a mild steel tube of 0·157 inch internal diameter was therefore used, and was joined at its base to a vessel containing mercury.

By causing water-pressure to act upon the surface of the mercury, it would rise gradually to the top of the tower. The inclination of the columns of the tower did not allow of the use of a vertical tube, but from the base to the first platform, a height of about 196 feet, the tube is fixed to the incline of one of the hoist rails, and an iron staircase follows its whole length. Between the first and second platforms, a height about equal to the former, the tube is fixed to the spiral staircase, which is divided into several parts not in the same vertical line; the tube is divided into the same number of parts, and is inclined at such an angle as to allow the mercury to descend freely. From the second platform to the summit the tube is fixed to the two large vertical spiral staircases. The height of the column of mercury cannot, of course, be observed in [illegible]l tube, so that it has been necessary to place try-cocks at [illegible] of about 10 feet apart, which communicate with glass tubes,

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and scales upon varnished wood are fixed at the side of these tubes. When the try-cocks are opened the glass tube is put in communication with the steel tube and the mercury rises, and its height can be read off. Detail drawings are given showing the method of fixing the tubes and try-cocks, which are protected by wood casing provided with doors, which can be opened when readings are to be made. In order to obtain a given pressure, the hydraulic pump is set to work slowly, and the mercury is caused to rise to the required height; if the mark is passed, a small quantity of water is let out by a cock fixed near the pump; the water which escapes rises in a vertical glass tube, which is graduated so as to indicate the corresponding level of the column of mercury itself. The operation is rendered very simple by means of a telephone, which the observer carries with him, and which can be placed at each try-cock in communication with the attendant below. If the mercury rises above the top of one of the glass tubes, it returns by an iron tube connected to the base of the apparatus. As the graduated scales fixed to the glass tubes are not all in a vertical line, the following plan has been used to calibrate the divisions.

The levels of certain points upon the Tower were obtained with great accuracy, and these were used as datum points. In order to calibrate two consecutive scales, two vessels filled with water were used, connected with each other by an india-rubber pipe; thus the horizontal plane corresponding to the top of one scale was made to agree with that of the bottom of the scale above. In the west column of the Tower, at the bottom of the gauge, is situated the laboratory, where are placed the hydraulic press, the mercury receiver, the telephone, and other accessories. A large metal pressure-gauge is connected to the hydraulic press; it is graduated both in atmospheres and also so as to indicate the precise try-cock above which the mercury has risen, so that it is always known upon which glass tube the reading must be taken. The temperature of the column of mercury during each test must be known, and this is measured by the variation in the resistance of the telephone wire, which runs close to it all along.

The instrument has been erected for purely scientific purposes, and Messrs. Mascart, Cailletet, Cornu and Hénocque, are now carrying on various experiments.

E. R. D.

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The Influence of Lightness upon the Cost of Construction of Vessels.

(Revue Maritime et Coloniale, vol. cviii., 1891 p. 352.)

In investigating the influence which is exercised upon the cost of a vessel by the weight of the material used in the construction of the hull and machinery, the ship is considered as having to carry a given load, consisting of guns, ammunition, and torpedoes, at a given speed, and with a given radius of action, and as being protected with armour of a given thickness.

The effect of an increase of weight of either the hull or the machinery upon the size and cost is first examined, and, a certain ship of war being taken as an example, it is shown that an augmentation of weight of hull of 10 per cent. raises the displacement by 13·6 per cent., and the cost by 26 per cent., while the same increase in weight of machinery involves an increase of 11 per cent. in the displacement, and of 28 per cent. in the cost.

It is pointed out that the increase in first cost does not represent completely the effect of increased displacement, since a larger crew and a larger consumption of fuel are entailed by it.

The probable effect of the substitution of aluminium for steel as a material for construction is discussed, and the assumption is first made that the two metals are of equal strength, and the scantlings therefore unchanged. Taking as an example the same ship as before, it is found that the adoption of aluminium for both hull and machinery would permit of the displacement being reduced to less than one half, and the first cost would remain the same if the price of aluminium did not exceed £333 per ton. There would still be a considerable economy resulting from the reduction in the crew and in the consumption of fuel. It is estimated that in the case of the ship in question, the saving under this head would amount in ten years to 20 per cent. of the first cost. Combining the economies in first cost and in maintenance for a period of ten years, the use of aluminium would commence to be advantageous at prices not exceeding £424 per ton.

On the assumption that aluminium has only half the strength of steel, and that in consequence the scantlings would require to be doubled, the first cost of the steel and aluminium vessels would be the same if the price of the latter material was £93 12*s.* per ton, or, taking into account maintenance for ten years as before, it might be as much as £153. The present price is £181, but there is every probability that a large increase in the demand for the material would lead to a great reduction in the cost of producing it.

S. W. B.

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The Causes of the Vibrations of Screw-Steamers.

By Assistant Naval Constructor D. W. TAYLOR, U.S. Navy.

(Journal of the American Society of Naval Engineers, vol. iii., 1891, p. 12.)

The Author divides the forces producing vibration into two classes:—

1. Those acting in the engine-room, and transmitted through the engine-framing to the structure of the ship.
2. Those acting upon the propeller, and transmitted through the bearings of the shaft to the structure of the ship.

The forces appearing in the engine-room are due to the inertia of the reciprocating parts. The practice, at one time common, of attempting to balance the weight of these parts by a weight fixed on the crank-shaft opposite the crank is not recommended, since new inertia forces equal to those destroyed will be introduced in a plane at right-angles to the axis of the cylinders, and since it is impossible to balance a reciprocating weight by a rotating weight.

It is considered desirable to balance only the uniformly rotating weight of the crank-pin and arms and half the connecting-rod in fast-running engines by means of counter-weights, and to balance the reciprocating parts by a reciprocating weight, which may conveniently take the form of an air-pump driven by a crank in a suitable position, its reciprocating parts being made sufficiently heavy. It is also suggested that four cylinders is the least number advisable in small, high-powered, and lightly-built ships.

In dealing with the second branch of the subject, namely, the tendency to vibration due to forces called into play by the action of the propeller, it is stated that when a symmetrical propeller is advancing steadily in a direction parallel to its axis with a constant turning moment through water which, when undisturbed by the propeller, has no motion, unless it be a uniform one parallel to the axis, the resultant of the reactions upon the propeller must be forces constant in direction and magnitude, or else constant turning couples. There is no tendency to vibration due to the action of such a propeller, but the actual conditions of working may differ from these imaginary conditions in any of the following respects:—

1. Lack of symmetry.
2. Non-uniformity of turning moment.
3. Axis not parallel to the direction of advance.
4. Non-uniformity and lack of parallelism of the race.

It is shown that an inclination of the shaft to the direction of advance varies the slip of the blades from point to point, and so produces a result analogous to a propeller working in a current where the velocity varies from point to point, as in the frictional wake of a vessel.

The effect is twofold. First, vibration is induced by a reciprocating vertical force, which is at a maximum when the blades are

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at 45°, and is zero when they are either vertical or horizontal; and secondly, a horizontal force is introduced which tends to turn the stern of the vessels sideways, and which varies from zero when the blades are horizontal to a maximum when the blades are vertical. The Author recommends that the axis of the shaft should be so inclined, both horizontally and vertically, as to counteract these forces, and gives a Table from which the necessary inclination may be obtained, depending upon the pitch and slip of the screw. On a twin-screw ship propellers which turn outwards should have the shaft deflected upwards and outwards, starting from the stern, while those which turn inwards should have their shafts inclined downwards and inwards if maximum uniformity of action is desired.

S. W. B.

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INDEX

TO THE

MINUTES OF PROCEEDINGS,

1890–91.—PART III.

Abt rack railway, 367.
Accumulators, charge-indicator for, 406.
Air, compressed.—"*The Transmission and Distribution of Power from Central Stations by Compressed Air*," Prof. W. C. Unwin (S.), 180.
Alternating-currents, power-transmission by, 417, 419.
Andrews, T.—"*Effect of Temperature on the Strength of Railway Axles*" (S.), 161.
Aqueduct.—"*The Construction of the New Nadrai (Kali Nadi) Aqueduct, Ganges Canal*," W. Good (S.), 147.—Well foundations, 147.—Grabs, 148.—Working of well-sinking plant, 151.—Weighting of the wells, 151.—Cost of well-sinking, 152.—Brickwork, lime, and mortar, 153.—Composition of concrete, 154.—Arched superstructure, 155.—Provision against leaks, 156.—Protecting works, 158.—Quantities and cost, 158.—Appendix: Results of test-loading wells after hearting, 160.
Arc, electric. See Electric arc.
Arching of bridges. "*Skew Arch Course Traces*," F. Harris (S.), 177.
Artesian wells. See Wells.
Atchison, A. T., memoir of, 320.
Auden, A. C., elected associate member, 2.
Audra, R., the Abt rack railway, 367.
Axles. See Railway axles.
Aytoun, R.—"*Securing the North Cliff, Scarborough*" (S.), 295.

Bacteriological investigation of the Röckner-Rothe system of sewage treatment at Potsdam, 336.
Baechtold, — von, the electric cables through the Gotthard tunnel, 413.
Bainbridge, C. E., elected member, 1.
Bale, G. R., admitted student, 1.
Bandyopadhyay, K., elected associate member, 2.
Baroscopic thermometer, a, 431.
Barrett. See Fox.
Bartlett, E. C., admitted student, 1.
Bazalgette, Sir J. W., C.B., reference to the death of, and resolution of sympathy with the family, 106.—Memoir of, 302.
Bechmann, —, pumping-stations and reservoirs for the improvement of the Paris water-supply, 344.
Belfield, R., elected associate member, 2.
Benham, A. H., elected associate member, 2.

Digitized by Google

Berkley, M. G., elected associate member, 2.
Berlin, Schwartzkopff system of sewage-treatment at, 340.—Disinfection of dwelling-houses in, 341.
Bernays, J.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Foundations in unsatisfactory soil, 132.
Berne, street tramway in, on the Mékarski system, 373.
Bertschinger, A., street tramway in Berne, on the Mékarski system, 373.
Blakesley, T. H.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London.*—London water-supply not entirely derived from the chalk, 58.—Capacity of the chalk to hold water understated by the Author, 59.
Blanchard and Lindsay, system of fire-proof construction, 271.
Blondlot, R., on the determination of the dielectric constant of glass for very rapid oscillations, 428.
Boilers. See Steam-boilers.
Bond, W., elected associate member, 2.
Bore-hole, temperature-measurements in a, at Sauerbrunn, 390.
Bosse and Wolters, manufacture of slag-cement, 215 *et seq.*
Breakwaters.—"*A Method of Constructing the Sub-aqueous part of Piers and Breakwaters with Soft Un-set Concrete,*" W. Kidd (S.), 231.
Brickwork. "*Skew Arch Course Traces,*" F. Harris (S.), 177.
Bridge-pier, repairing the foundations of a, 329.
Bridges, brick. "*Skew Arch Course Traces,*" F. Harris, (S.), 177.
———, railway. See Railway bridges.
Brodie, J. B., admitted student, 1.
Brunton, R. H.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Danger of Molyneaux composition, 133.—Disadvantages of chalk and ballast foundation, 133.
Brussels, water-supply of, 347.
rylinski, E., note on an underground line laid in a cement conduit, 427.
Budapest electric-tramways, 424.
Buildings, protection of, from lightning, 427.
Bulfin, I., admitted student, 1.
"Bunnett" floor for fire-proof buildings, 265, 269.

Cable- and electric-railways, 422.
———, electric. An underground line laid in a cement conduit, 427.
Cables, electric, through the Gotthard tunnel, 413.
Cailletet, —, the soldering of glass and porcelain tubes to metals, 428.—Cryogene, 429.
Caisson without timber or iron in its construction, 327.
Calcined infusorial earth, filters of, 335.
California, Southern, irrigation in, 238 *et seq.*
Canal, Ganges.—"*The Construction of the New Nadrai (Kali Nadi) Aqueduct, Ganges Canal,*" W. Good (S.), 147.
———, Marne and Saône, works on the, 354.
Carne, F. W., elected associate member, 2.
Carnegie, D., admitted student, 1.
Carpmael, H. G., elected associate member, 2.
Carrington, W. T. H.—"*The Reception and Storage of Refined Petroleum in Bulk,*" 108.—*Discussion on ditto:* Gauge-tubes an element of weakness in tanks,

Digitized by Google

119.—Advantages of tank system of transport, 120.—Ocean transport, 121.—Discharge of cargo, 121, 134.—Difficulties of inspection and measurement, 122, 134.—Safety of tank-storage in case of fire, 123.—Tanks in the Canadian oil-fields, 123.—Tanks for the Mersey Docks Board, 125.—Advantage of machine-riveting, 127.—New system of gauging, 127.—Crane for lifting plates into position, 127.—Weight of petroleum, 128.—Conditions of construction of tanks, 130.—Gauge to avoid perforating the tank, 131.—Foundations in unsatisfactory soil, 132.—Molyneaux paint, 133, 135.—Disadvantages of chalk and ballast foundation, 133.—Preference for pipe-line above ground, 135.—Gridiron series of drains below foundations, 136.—*Correspondence:* Concrete walls alone not a protection from fire, 137, 146.—Statistics as to petroleum in Eastern Europe, 138.—Composition and properties of petroleum and petroleum refuse, 138.—Products, 138.—Construction of reservoirs, 139.—Objections to the use of cast-iron for manholes, 140, 146.—Westphale's instrument for measuring specific gravity, 141.—Tables showing extent of petroleum industry in Russia for 1889, 143.

Cement. See Slag-cement.

——— conduit, an underground line laid in a, 427.

Chalk formation of the Upper Thames.—"*On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*," J. T. Harrison, 2.

Charge-indicator for accumulators, 406.

Chemical and bacteriological investigation of the Röckner-Rothe system of sewage-treatment at Potsdam, 336.

Clarifying sewage-water at Frankfort-on-Main, 338.

Cliff.—"*Securing the North Cliff, Scarborough*," R. Aytoun (S.), 295.

——. See also Sea-wall.

Clutch. See Safety-clutch.

Cobalt ore, new process for the treatment of, 396.

Cofferdam without timber or iron in its construction, 327.

Coke-breeze, as fuel, 381.—Utilization of, 383.

Cole, H. G., elected associate member, 2.

Colebrook, H. W. V., elected member, 1.

Collis, W. H., elected associate member, 2.

Compressed air. See Air.

Concrete briquettes, summary of tests of, 258.

——— in the construction of piers, &c.—"*A Method of Constructing the Sub-Aqueous part of Piers and Breakwaters with Soft Un-set Concrete*," W. Kidd (S.), 231.—*Appendix:* Concrete in superstructure, 236.—Measurement of mixed materials in concrete test-block, 236.—Tensile strength of concrete, 237.

Construction. See Fire-proof Construction.

Copland, W. R., Jun., admitted student, 1.

Coquerel gas-plant, 385.

Craven, A. W., elected associate member, 2.

Crighton, C., admitted student, 1.

Crimp, W. S.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Gaugings of the Wandle, 55.—Amount available for water-supply in the upper reaches of the Thames over-estimated, 56.

Crosby, O. T., high-speed electric-railway work, 421.

Cryogene, Cailletet's, 429.

Digitized by Google

Dadley, B. B., elected associate member, 2.
Darton, N. H., Florida phosphate-deposits, 391.
Davies, D., elected associate member, 2.
Dawkins, Prof. W. B.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*: Amount of water in the chalk available for economic purposes, 87.
"Dawnay" system of fire-proof construction, 266.
Decugis, L., Pastore's water-meter for minimized loss of pressure, 342.
Deflection-tests, results of, on loaded railway bridges, 331.
Dennett and Ingle, system of fire-proof construction, 268.
Desulphurizing molten cast-iron, 398.
Dielectric constant of glass for very rapid oscillations, 428.
Disinfection of dwelling-houses in Berlin, 341.
Dolivo-Dobrowolsky, M. von, power-transmission by alternating-currents, 417.
Douglas, G., admitted student, 1.
Doulton & Co., system of fire-proof construction, 270.
Drainage experiments, Dr. Gilbert's, at Rothamsted, 31.
——— of the lake in the Tedingerbroek, Holland, 353.
Drive, Royal Albert, Scarborough, 289 *et seq.*
Drouin, F., Siemens dynamo with internal field-magnets, 407.
Dryland, A., elected associate member, 2.
Ducretet signal switch-board, 412.
Dwelling-houses, disinfection of, in Berlin, 341.
Dynamo, Siemens, with internal field-magnets, 407.

Earth, calcined infusorial, filters of, 335.
Easton, J. R., elected associate member, 2.
Eiffel Tower, pressure-gauge on the, 432.
Electric arc, photographic study of the, based upon experiments made by Mr. J. C. McMynn, 425.
——— -lighting of railway-trains, 416.
——— -light station, central, at Hanover, 413.
——— ——— ———, municipal, at Paris, 414.
——— -railway work, high speed, 421.
——— -railways, 422.
——— -tramways, the Budapest, 424.
——— -welding. See Welding.
——— -wiring. See Wiring.
——— cables. See Cables.
Electricity. A charge-indicator for accumulators, 406.
———. Apparatus for telephone exchanges, 408.
———, direct conversion of heat into, 404.
———. Giraud's thermo-electric stove, 426.
———. Note on an underground line laid in a cement conduit, 427.
———. Power-transmission by alternating-currents, 417, 419.
———. Some possible modifications in the methods of protecting building from lightning, 427.
———. The Ducretet signal switch-board, 412.
———. The repair of glow-lamps, 417.
———. Siemens and Halske safety-clutch, 408.
———. Siemens dynamo with internal field-magnets, 407.

Digitized by Google

Electrolytic method, new, of determining metals, 401.
Eliot, W.—"*The North Sea-Wall and Royal Albert Drive, Scarborough*" (S.), 289.
Embankment, the North Sea-wall, Scarborough, 289 *et seq.*
Engines. See Steam-engines.
Evans, Dr. J.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Objections to vagueness of several of the Author's statements, 59.—Angle of friction of water in a porous body, 60.—Water absorbed by vegetation, 61.—Objections to the Author's theories as to the gravel-beds at Datchet and Slough, 62.—Water abstracted from underground must affect the streams on the surface, 62.
Ewing, Prof. J. A., B.Sc., F.R.S., elected member, 1.

Farrell, R.C., admitted student, 1.
Field-magnets, internal, Siemens dynamo with, 407.
Filtration of water through filters of calcined infusorial earth, 335.
"*Fire-proof Construction,*" J. J. Webster (S.), 249.—Fire-resisting properties of the various materials used, 250.—Cast-iron, wrought-iron, and steel, 250.—Stone, 253.—Brick, 255.—Concrete, 256.—Summary of tests of concrete briquettes, 258.—Terra-cotta, 259.—Plaster, 259.—Timber, 260.—Asbestos and silicate cotton, 262.—Structural combination of materials, 262.—Arch pots, 264.—Fox and Barrett system, 265.—Bunnett floor, 265, 269.—Which-cord casing for ironwork of girders, 266.—Dawnay system, 266.—Systems of Phillips, Homan and Rodgers, and W. H. Lindsay and Co., 267.—Ditto of R. Moreland, Jun., Vaux and Thuasne, and Dennett and Ingle, 268.—Ditto of Hyatt, 269.—Ditto of Hornblower, Northcroft, and Doulton and Co., 270.—Ditto of Blanchard and of W. Lindsay, Jun., 271.—Hollow tile flat arch system, 272.—Maurer system, 272.—"Raritan" system, 273.—Application of silicate cotton, 274.—Wire-netting instead of laths, 274.—Solid wood construction, 275.—Columns, 276.—Partitions, 276.—Roofs and ceilings, 276.—Doors and window-shutters, 277.—Fire-proof theatre-curtains, 277.—General arrangement of the structures, 279.—General conclusions, 280.—*Appendix:* Tables of tests of materials, 283.
Fitzgerald, J. L., comparison of water-supply systems from a financial point of view, 349.
Flachat, E., the schiseophone, 430.
Florentin, A., works on the Marne and Saône canal, 354.
Florida phosphate-deposits, 391.
Flower, Major L.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Very little variation in the level of the Banstead well, 71.—Danger of pollution by surface-water, 71.
Forrest, W. R. L., admitted student, 1.
Forrester, A. L., admitted student, 1.
Foundations, repairing the, of a bridge-pier, 329.
Fox, W.—"*Irrigation in Southern California, with Special Reference to the Artesian Wells in San Bernardino County*" (S.), 238.
Fox and Barrett, system of fire-proof construction, 265.
Frankfort-on-Main, clarifying sewage-water at, 338.
Frère, G., coke-breeze as fuel, 381.
Fuel, coke-breeze as, 381.

Digitized by Google

Gales, R. R., elected associate member, 2.
Gamble, F. C., elected member, 1.
Gardner, J. W. F., admitted student, 1.
Garforth, W. E., elected member, 1.
Gas-plant, the Coquerel, 385.
Gauges. See Rain-gauges.
Gernaert, J., water-supply of Brussels and its suburbs, 347.
Gilbert, Dr. J. H.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Twenty years of percolation experiments at Rothamsted, 31.—Summary of results, 35.—Explanation of Tables, 47.
Giraud's thermo-electric stove, 426.
Glass, dielectric constant of, for very rapid oscillations, 428.
Glow-lamps, the repair of, 417.
Godfrey, A. H., elected associate member, 2.
Gold and platinum industry of the Ural, 391.
Good, W.—"*The Construction of the New Nadrai (Kali Nadi) Aqueduct, Ganges Canal*" (S.), 147.
Goodson, T., apparatus for the prevention of the waste of water in closets and from taps, 343.
Grantham, R. F.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Effects of pumping in wells in the chalk in Essex, 71.—Subsoil water in the neighbourhood of Slough, 71.
Gray, H. A., elected member, 1.
Gülcher, R. J., the direct conversion of heat into electricity, 404.
Gutermuth, Prof., experiments on the resistance of the Paris air-mains, 189.—Ditto on the efficiency of compressors, 200.
Gutta-percha, the applications of, 420.

Halske. See Siemens.
Hanover, central electric-light station at, 413.
Harbottle, J., admitted student, 1.
Harbour works near Saltburn-by-the-Sea, 231.
Harper, E. L., memoir of, 323.
Harris, F., B.A.—"*Skew Arch Course Traces*" (S.), 177.
———, R. L., elected member, 1.—Cofferdam or caisson without timber or iron in its construction, 327.
Harrison, J. T.—"*On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London,*" 2.—*Discussion on ditto:*—Explanation of illustrations, 26.—Percolation experiments, 29.—Gaugings of the Wandle, 30, 55, 85.—Twenty years of percolation experiments at Rothamsted, 31, 60, 69, 84.—Summary of results, 35.—Mean annual rainfall in the chalk area of the Thames Basin West and North of London (1880–89), 49.—Wendover springs, 52, 84.—Evaporation from the soil, 54.—Effect of pumping water from the mountain limestone at the Severn Tunnel, 57.—London water-supply not entirely derived from the chalk, 58, 73.—Angle of friction of water in a porous body, 60.—Water in the gravel-beds, 62, 82.—Quantity of water pumped from the chalk in private wells in London, 66.—Increment received by the Thames between Teddington and Kew, 67, 70, 74.—Chalk springs at Havant, 68.—Effects of pumping in wells in the chalk in

Digitized by Google

Essex, 71.—Gaugings between Teddington and Kew, 75.—Porous gravel above Kew, 77.—Supply from the Slough gravel-bed, 81.—Conditions of withdrawal of water from the chalk, 82.—*Correspondence on ditto*:—Amount of water in the chalk available for economic purposes, 87, 96.—Quantity of water unaccounted for, 88, 97.—Attempt to obtain water by well-making at Swindon, 89.—Transmission of water through the chalk, 91.—Proportion of rainfall percolating into the chalk, rocks, and gravel beds, 93.—Absorbing and retentive capacities of gravel-beds, 93.—Comparative analyses of water, 98.

Hart, P. C., admitted student, 1.

——, T., admitted student, 1.

Hawkshaw, J. C.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*:—Effect of pumping water from the mountain limestone at the Severn Tunnel, 57.

Heat, direct conversion of, into electricity, 404.

Heaton, F. G., admitted student, 1.

Henwood, E. N.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk*:—Form of gauge to avoid perforating the tank, 131.

Hernu, A. H., elected associate member, 2.

Hildred, E. T., elected associate member, 2.

Hodges, N. C. D., possible modifications in the methods of protecting buildings from lightning, 427.

———, P. W. O., elected associate member, 2.

Hogan, J. P. L., transferred member, 1.

Homan and Rodgers, system of fire-proof construction, 267.

Hopkinson, J.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*:—Rainfall in Hertfordshire, 48.—Mean annual rainfall in the chalk area of the Thames Basin West and North of London (1880–89), 49.

"Hornblower" system of fire-proof construction, 270.

Hospitalier, E., charge-indicator for accumulators, 406.—Giraud's thermo-electric stove, 426.

Houses, dwelling-, disinfection of, in Berlin, 341.

Hull, Professor E.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*:—Quantity of water unaccounted for in the Chalk basin, 88.

Humphreys, H. H., admitted student, 1.

Hunt, A. E., elected member, 1.

——, C. B., repairing the foundations of a bridge-pier, 329.

Hutchins, F., admitted student, 1.

"Hyatt" system of fire-proof construction, 269.

Hydraulic work and inland navigation in Italy, 357.

Indicator, charge-, for accumulators, 406.

Ingle. See Dennett.

Infusorial earth, filters of, 335.

Inland navigation in Italy, 357, 360.

Interior-Conduit and Insulation Company's system of electric-wiring, 410.

Iron. Desulphurizing molten cast-iron, 398.

"*Irrigation in Southern California, with Special Reference to the Artesian Wells in San Bernardino County*," W. Fox (S.), 238.—Quantity of water required for irrigation, 238.—Artesian wells, 240.—Driving tunnels, 243.—Storage-reser-

Digitized by Google

voirs, 243.—Diversion of rivers, 244.—Modes of carrying water, 245.—Modes of distribution, 246.
Italy, hydraulic work and inland navigation in, 357, 360.

Jackson, J., memoir of, 324.
Johnson, E. H., the system of electric-wiring of the Interior-Conduit and Insulation Company, 410.
Joints, riveted, in boiler-shells, 388.
Joseph, L. L., admitted student, 1.
Judson, W. P., elected member, 1.

Kassner oxygen process, 399.
Kebby, H. M., cable- and electric-railways, 422.
Kidd, W.—"*A Method of Constructing the Sub-Aqueous part of Pier and Breakwaters with Soft Un-set Concrete*" (S.), 231.
Kohlrausch, W., central electric-light station at Hanover, 413.
Korevaer, P. A., drainage of the lake in the Tedingerbroek, Holland, 353.
Korte, C., comparative working-expenses of small motors, 375.
Kuntze, —, lubrication with mineral oil, 386.
———, A., State railway on the West Coast of Sumatra, 370.

Lagarde, —, the applications of gutta-percha, 420.
Lake in the Tedingerbroek, Holland, drainage of, 353.
Lamps. See Glow-lamps.
Landslips.—"*Securing the North Cliff, Scarborough*," R. Aytoun (S.), 295.
Laurent, —, the gold and platinum industry of the Ural, 391.
Leete, W. H., elected associate member, 2.
Lepsius, Dr. B., systems of clarifying sewage-water at Frankfort-on-Main, 338.
Leslie, R. F., elected associate member, 2.
Le Van, W. B., riveted joints in boiler-shells, 388.
Lewis, L. W., admitted student, 1.
Lightning, protection of buildings from, 427.
Lindley, J., elected member, 1.
Lindsay, —. See Blanchard.
———, W. H. & Co., system of fire-proof construction, 267.
Lloyd, B. G., elected associate member, 2.
Lubrication of engines, 387.
———— with mineral oil, 386.
Lucas, J.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*: Area of supply to the Wendover springs, 52.—Results of gaugings of the Wandle different from those of the Author, 53.—Evaporation from the soil, 54.—Area of the Wandle, 57.
———, L. D., admitted student, 1.

McMynn, J. C., photographic study of the electric arc, based upon experiments made by, 425.
Magnets. See Field-magnets.
Mamy, H., the Ducretet signal switch-board, 412.
Manara, E., hydraulic work and inland navigation in Italy, 357.
Mansergh, J.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*: Percolative gaug-

Digitized by Google

ings should be made in land with growing crops, 69.—Objections to abstracting from the ground the water flowing into the Thames between Teddington and Kew, 70.—Questions as to the gaugings made by the Author, 70.
Marley, J., memoir of, 308.
Marne and Saône canal, works on the, 354.
Marsh, T. E. M.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Attempt to obtain water by well-sinking at Swindon, 89.
Massachusetts, organisms in the waters of, 333.
"Maurer" system of fire-proof construction, 272.
Mead, A. S., admitted student, 1.
Meade, T. de C., transferred member, 1.
Měkarski system, street tramway on the, in Berne, 373.
Merke, H., disinfection of dwelling-houses in Berlin, 341.
Mersey Docks, tanks for the storage of petroleum at the, 125.
Metals, new electrolytic method of determining, 401.
———, soldering of glass and porcelain tubes to, 428.
Meteorological Society (Royal), list of rain-gauges, evaporation-gauges, &c., exhibited by the, 100.
Meter. See Water-meter.
Meyer, F., the municipal electric-lighting station at Paris, 414.
Michele, V. de.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Question as to exposure of tanks to the atmosphere, 130.
Miller, R. F., admitted student, 1.
Mineral oil. See Oil.
Molyneaux paint, 133, 135.
Montpellier, J. A., the repair of glow-lamps, 417.
Moreland, R., Jun., system of fire-proof construction, 268.
Morton, H. J., admitted student, 1.
Motors, small, comparative working-expenses of, 375.
Murray, F. C., elected member, 1.

Nansouty, M. de, Cailletet's cryogene, 429.—The pressure-gauge on the Eiffel Tower, 432.
Napier, A. S., elected associate member, 2.
Navigation, inland, in Italy, 357, 360.
Nichols, Prof. E. L., a photographic study of the electric arc based upon experiments made by Mr. J. C. McMynn, 425.
Nocht, Dr. See Proskauer.
Nordtmeyer, Dr. H., filtration of water through filters of calcined infusorial earth, 335.
"Northcroft" system of fire-proof construction, 270.

Oil, mineral, lubrication with, 386.
——. See Petroleum.
Ore, cobalt, new process for the treatment of, 396.
Organisms in the waters of Massachusetts, 333.
Oxygen, manufacture of, the Kassner process, 399.

Paris, municipal electric-lighting station at, 414.
——— water-supply, pumping-stations and reservoirs for the improvement of the, 344.

Digitized by Google

Parker, C., elected associate member, 2.
———, G. H., organisms in the waters of Massachusetts, 333.
Parkin, F. W., elected associate member, 2.
Paschen, E., results of deflection-tests on loaded railway bridges, 331.
Pastore's water-meter for minimized loss of pressure, 342.
Peirce, M.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Mode of taking the gaugings between Teddington and Kew, 75.
Pelleton, L., new process for the treatment of cobalt ore, 396.
Percolation experiments, Dr. Gilbert's, at Rothamsted, 31.
Perkins, L., memoir of, 311.
Perrine, Dr. F. A. C., the practical aspects of electric welding, 403.
Petroleum. "*The Reception and Storage of Refined Petroleum in Bulk,*' W. T. H. Carrington, 108.—Reception, 108.—Storage, 110.—Construction of tanks, 111.—Testing, 113.—Delivery, 115.—Distribution in bulk by means of tank carts, 117.—*Appendix:* Sizes and dimensions of various petroleum tanks, 118.—*Discussion:* W. T. H. Carrington, 119, 134; B. Redwood, 120; S. H. Terry, 125; V. de Michele, 130; J. J. Webster, 130; E. N. Henwood, 131; J. Bernays, 132; B. P. Stockman, 133; R. H. Brunton, 133.—*Correspondence:* J. F. Redman, 137; B. B. Stoney, 137; T. Urquhart, 137; W. T. H. Carrington 145.
Pettré, J., utilization of coke-breeze, 383.
"Phillips" system of fire-proof construction, 267.
Phosphate-deposits of Florida, 391.
Photographic study of the electric arc based upon experiments made by Mr. J. C. McMynn, 425.
Pier, bridge-, repairing foundations of a, 329.
Piers. "*A Method of Constructing the Sub-aqueous part of Piers and Breakwaters with Soft Un-set Concrete,*" W. Kidd (S.), 231.
Platinum industry of the Ural, 391.
Pollution and self-purification of streams, 331.
Potsdam, Röckner-Rothe system of sewage-treatment at, 336.
Power.—"*The Transmission and Distribution of Power from Central Stations by Compressed Air,*" Prof. W. C. Unwin, (S.), 180.—Combined efficiency of compressor main and motor, 180.—Means of reducing the temperature of air during compression, 181.—Loss of pressure in the air mains, 182.—Formula for the flow of air in long pipes, 183.—Loss of air by leakage from the main, 187.—Correction for loss of pressure at draining-tanks, 188.—Experiments on the resistance of the Paris air mains, 189.—Loss of pressure per mile of pipe, 192.—Action of the air-compressors, 193.—Experiments on the efficiency of compressors, 200.—Action of the air-motors, 201.—Useful work done by an air-motor, 203.—Small rotating air-motors, 205.—Practical calculations, 207. Values assumed for the coefficients of efficiency, 208.
Power-transmission by alternating currents, 417, 419.
Pressure, gauge on the Eiffel Tower, 432.
Preston, F. J., elected associate member, 2.
Prestwich, Prof. J.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Faults in the tertiary strata and in the chalk of the Thames Basin, 90.—Transmission of water through the chalk, 91.—Supply available from the chalk, 91.

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Prigg, H. V., elected associate member, 2.
Pritchard, P. M., admitted student, 1.
Proskauer, B., and Dr. Nocht, chemical and bacteriological investigation of the Röckner-Rothe system of sewage-treatment at Potsdam, 336.—Schwartzkopff system of sewage-treatment (Berlin), 340.
Puluj, Dr. J., temperature-measurements in a bore-hole at Sauerbrunn, 390.
Pumping-stations and reservoirs for the improvement of the Paris water-supply, 344.
Purification, self-, of streams, 331.

Rack railway. See Railway.
Radcliffe, A. N., elected associate, 2.
Railton, A., elected associate member, 2.
Railway, Abt rack, 367.
——— axles.—"*Effect of Temperature on the Strength of Railway Axles*," T. Andrews (S.), 161.—Conditions of experiments, 161.—Method, 161.—Cold tests, 162.—Warm tests, 162.—General summary of results, 164.—Instances of fractures, 167.—*Appendix:* Table of cold tests, 169.—Table of warm tests, 174.
——— bridges, results of deflection-tests on loaded, 331.
———, electric. See Electric Railway.
———, State, on the West Coast of Sumatra, 370.
——— trains, electric-lighting of, 416.
Railways.—"*The Lanarkshire and Ayrshire Railways*," W. A. P. Tait (S.), (abstract), 298.—Viaduct over the River Garnock, 300.—Construction of bridges under the Glasgow and South Western Railway, 300.—Cost of works, 301.
———, cable-. See Cable-railways.
Rainfall, experiments as to, by Dr. Gilbert at Rothamsted, 31.
——— in the chalk area of the Thames Basin West and North of London (1880–89), Table showing the mean annual, 49.
Rain-gauges, evaporation-gauges, &c., list of, exhibited by the Royal Meteorological Society, 100.
"Raritan" system of fire-proof construction, 273.
Reade, T. M.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Quantity of water required to produce saturation of the chalk and of the new red sandstone, 92.—Objections to incompleteness of data, 92.
Redgrave, G. R.—"*The Manufacture and Properties of Slag-cement*" (S.), 215.
Redman, J. F.—*Correspondence on the Reception and Storage of Refined Petroleum in Bulk:* Necessity for a rampart of earth round storage places, 137.
Redwood, B.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Advantages of tank system of transport, 120.—Ocean transport, 121.—Discharge of cargo, 121.—Difficulties of inspection and measurement, 122.—Comparative safety of tank-storage in case of fire, 123.—Tanks in the Canadian oil-fields, 123.—Advantages of barrel system, 124.
Reid, A. G. W., C.M.G., elected member, 1.
Rennie, W. C., memoir of, 314.
Reservoirs for the improvement of the Paris water-supply, 344.
Richter, E., the Siemens and Halske safety-clutch, 408.

Digitized by Google

Riedler, Prof., experiments on the resistance of the Paris air mains, 189.—Ditto on the efficiency of compressors, 200.
River Thames.—"*On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*," J. T. Harrison, 2.
——— ———, gaugings of the volume of water at Kew, 77.
Rivers of Massachusetts, organisms in the, 333.
———, pollution and self-purification of, 331.
Riveted joints. See Joints.
Robertson, T. B., admitted student, 1.
Robinson, Prof. H.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* The Black Pot Tunnel driven in an impervious stratum above the chalk, 73.
Röckner-Rothe system of sewage treatment at Potsdam, 336.
Rodgers. See Homan.
Ross, C. J., B.E., B.Sc., elected associate member, 2.
Roussel, E., testing steel tires, 389.

Safety-clutch, the Siemens and Halske, 408.
Saltburn-by-the-Sea, harbour works at, 231.
Saône canal. See Marne and Saône Canal.
Sauerbrunn, temperature-measurements in a bore-hole at, 390.
Scarborough, North Sea-wall and Royal Albert Drive, 289 *et seq.*—Securing the North Cliff at, 295 *et seq.*
Schiseophone, the, 430.
Schofield, G. A., elected associate member, 2.
Schwartzkopff system of sewage-treatment (Berlin), 340.
Screw-Steamers. See Steamers.
Sears, R. H., Jun., admitted student, 1.
Sea-wall. "*The North Sea-wall and Royal Albert Drive, Scarborough.*" W. Eliot, (S.), 289.—Sea-wall, 289.—Road and promenade, 291.—Slipways and steps, 292.—Drainage of surface-water, 293.—Approach to iron pier, 293.—Effect on foreshore, 293.—Cost of works, 294.—Quantities of work, 294.
———. See also Cliff.
Sewage treatment, Röckner-Rothe system of, at Potsdam, 336.
——— ———, Schwartzkopff system (Berlin), 340.
——— -water, clarifying, at Frankfort-on-Main, 338.
Shaw, G., admitted student, 1.
Sheilds, F. Wentworth-.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Remarks as to objections that if the lower strata were tapped the higher beds would be drained of water, 72.
Ships. See Vessels.
Siemens dynamo with internal field-magnets, 407.
——— and Halske safety-clutch, 408.
Simpson, M. H., elected associate member, 2.
Slag-cement.—"*The Manufacture and Properties of Slag-Cement*," G. R. Redgrave (S.), 215.—Slag used to adulterate cement, 215.—Cementitious properties of slag, 215.—Bosse and Wolters' method, 215.—Comparison of composition of slag-cement and Portland cement, 219.—Chemistry of the action of cements made from slag, 219.—Other considerations influencing the behaviour of slag, 221.—Loss in tensile strength due to protracted exposure to the atmosphere,

Digitized by Google

223.—Method of testing hardness adopted in Germany, 224.—Sand capacity, 225.—*Appendixes:* Analyses of blast-furnace slags from Carron Works, 226.—Analyses of English slags, 226.—Results of tests in lbs. per square inch, 227.—Investigation by the Royal Testing Establishment for building materials at Berlin, 227.

Slaughter, E., memoir of, 316.

Smith, E. F., new electrolytic method of determining metals, 401.

Soldering of glass and porcelain tubes to metals, 428.

Sowerby, W.—*Correspondence on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Proportion of rainfall percolating into the chalk rocks and gravel-beds, 93.—Absorbing and retentive capacities of gravel-beds, 93.—Necessity for subsidiary or compensatory works, 94.

Stang, T., quantity of water available in sandy soils, and its utilization for the supply of towns, 352.

Steam-boiler-shells, riveted joints in, 388.

——— -engines, lubrication of, 387.

Steamers, screw-, causes of the vibrations of, 435.

Stearns, F. P., pollution and self-purification of streams, 331.

Steel tires, testing, 389.

Stirling, J. L., admitted student, 1.

Stockman, B. P.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Composition of Molyneaux paint, 133.

Stoney, B. B.—*Correspondence on the Reception and Storage of Refined Petroleum in Bulk:* Concrete walls alone not reliable as a protection from fire, 137.

Stove, Giraud's thermo-electric, 426.

Streams of Massachusetts, organisms in the, 333.

———-, pollution and self-purification of, 331.

Street tramway. See Tramway.

"*Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London,*" J. T. Harrison, 2.

Sumatra, State railway on the West Coast of, 370.

Switch-board, the Ducretet signal, 412.

Symons, G. J.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* Percolation experiments at Rothamsted, 29.—Gaugings of the Wandle, 30.—Increase of water between Teddington and Kew, 31.

Tait, W. A. P., B.Sc.—"*The Lanarkshire and Ayrshire Railways*" (S.) (abstract), 298.

Taylor, D. W., causes of the vibrations of screw-steamers, 435.

Tedingerbroek, Holland, drainage of the lake in the, 353.

Telephone-exchanges, apparatus for, 408.

Temperature, effect of, on the strength of railway axles, 161.

———— -measurements in a bore-hole at Sauerbrunn, 390.

Terry, S. H.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk:* Tanks constructed for the Mersey Docks Board, 125.—Advantage of machine-riveting, 127.—New system of gauging, 127.—Crane for lifting plates into position and for carrying pneumatic riveter, 127.—Weight of petroleum, 128.

Digitized by Google

Thermo-electric stove, Giraud's, 426.
Thermometer, a baroscopic, 431.
Thomas, T. F., elected associate member, 2.
———, W. M., admitted student, 1.
Thompson, J., B.E., elected associate member, 2.
Thorrold, S. E., elected associate member, 2.
Thuasne. See Vaux.
Tires, testing steel, 389.
Topley, W.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London:* The existence of water in the gravel, 73.—Increment of water in the Thames between Kingston and Kew, 74.—Objections to deductions from the Author's gaugings, 74.
Touanne, G. de la, apparatus for telephone-exchanges, 408.
Tower, Eiffel, pressure-gauge on the, 432.
Towns, water-supply of, from sandy soils, 352.
Trains. See Railway-trains.
Tramway, street, in Berne, on the Mékarski system, 373.
Tramways, electric-. See Electric-tramways.
Truninger, L., admitted student, 1.
Tubes, glass and porcelain, soldering of, to metals, 428.
Tunnel, Gotthard, electric cables through the, 413.
Tunner, P., desulphurizing molten cast-iron, 398.
Turner, A., admitted student, 1.

Unwin, Prof. W. C., B.Sc.—"*The Transmission and Distribution of Power from Central Stations by Compressed Air*," (S.), 180.
Uppenborn, F., electric-lighting of railway-trains, 416.—The Budapest electric-tramways, 424.
Ural, the gold and platinum industry of the, 391.
Urquhart, T.—*Correspondence on the Reception and Storage of Refined Petroleum in Bulk:* Statistics as to petroleum in Eastern Europe, 138.—Composition and properties of petroleum and petroleum refuse, 138.—Products, 138.—Construction of reservoirs, 139.—Objections to the use of cast-iron for manholes, 140.—Westphale's instrument for measuring specific gravity, 141.—Tables showing extent of petroleum industry in Russia for 1889, 143.

Vaux and Thuasne, system of fire-proof construction, 268.
Vessels, influence of lightness upon the cost of construction of, 434.
Vesian, J. S. E. de, elected associate member, 2.
Vibrations of screw-steamers, causes of the, 435.
Vitoux, G., Coquerel gas-plant, 385.

Walker, B., memoir of, 317.
Water available in sandy soils, and its utilization for the supply of towns, 352.
———, filtration of, through filters of calcined infusorial earth, 335.
———, subterranean. "*On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*," J. T. Harrison, 2.—Previous Projects, 3.—Quantity of Water held by the chalk, 4.—Proportion of rainfall sinking into the chalk, 6.—Explanation of map showing chalk-

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basin westward of London, 10.—Escape of surplus water, 13.—Gravel-bed and underground river below Datchet, 14.—Slough gravel-reservoir and underground river, 16.—Source of supply of reservoirs, 17.—System of collection for London supply, 22.—*Appendix:* Gaugings of the Thames, 25.—*Discussion:* Sir J. Coode, 26; J. T. Harrison, 26, 76; G. J. Symons, 29; Dr. J. H. Gilbert, 31, 52; J. Hopkinson, 48; J. Lucas, 52, 56; W. S. Crimp, 55; J. C. Hawkshaw, 57; T. H. Blakesley, 58; Dr. J. Evans, 59; W. Whitaker, 63; J. Mansergh, 69; Major L. Flower, 71; R. F. Grantham, 71; F. Wentworth-Sheilds, 72; Prof. H. Robinson, 73; W. Topley, 73, 76; M. Peirce, 75.—*Correspondence:* Prof. B. Dawkins, 87; Prof. E. Hull, 88; T. E. M. Marsh, 89; Prof. J. Prestwich, 90; T. M. Reade, 92; W. Sowerby, 93; J. T. Harrison, 96.—List of rain-gauges, &c., exhibited in illustration of the Paper, 100.

Water, waste of, apparatus for the prevention of, 343.

——. See also Sewage-water.

Water-meter, Pastore's, for minimized loss of pressure, 342.

——-supply of Brussels, 347.

——————— London. "*On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*," J. T. Harrison, 2.

——————— of towns from sandy soils, 352.

——————— Paris, pumping-stations and reservoirs for the improvement of the, 344.

——————— systems, comparison of, from a financial point of view, 349.

Waters of Massachusetts, organisms in the, 333.

Webster, J. J.—*Discussion on the Reception and Storage of Refined Petroleum in Bulk*:—Preference for hydraulic-riveter, 130.—Convenience of placing pipe-lines in trenches, 130.—Conditions of construction of tanks, 130.—"*Fire-proof Construction*" (S.), 249.

Welding, electric, practical aspects of, 403.

Wells, artesian, in San Bernadino County, Southern California, 238 *et seq.*

——. See also Bore-hole.

Westphale's instrument for measuring specific gravity of petroleum, 141.

Wheeler, G. U., admitted student, 1.

"Whichcord" casing for ironwork of girders in fire-proof buildings, 266.

Whitaker, W.—*Discussion on the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London*:—Objections to several of the Author's statements, 63.—Quantity of water pumped from the chalk in private wells in London, 66.—Increment received by the Thames between Teddington and Kew, 67.—Chalk springs at Havant, 68.

Wickham, P. F., admitted student, 1.

Wilson, A., elected associate member, 2.

Wiring, electric-, system of the Interior-Conduit and Insulation Company, 410.

Wolters, Bosse and, manufacture of slag-cement, 215 *et seq.*

Woodcock, W. H., elected member, 1.

Wray, G. B. S., admitted student, 1.

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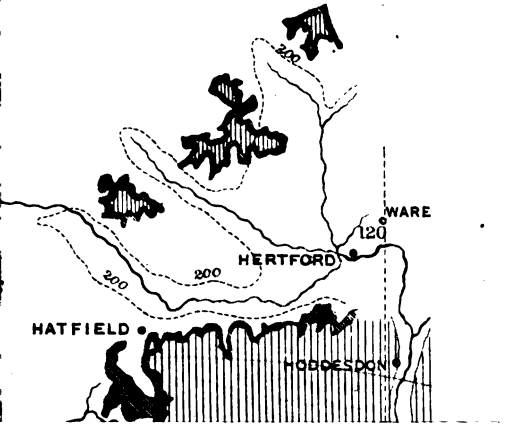

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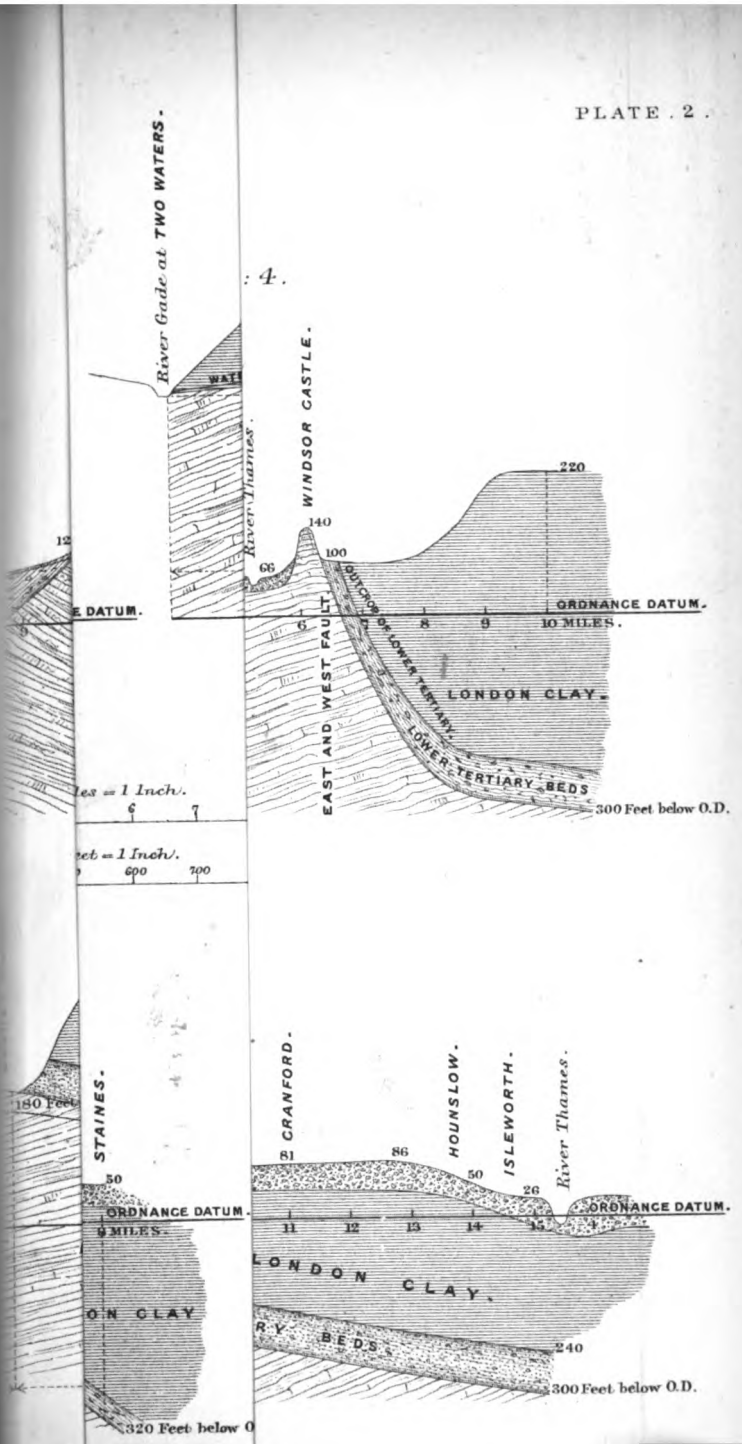

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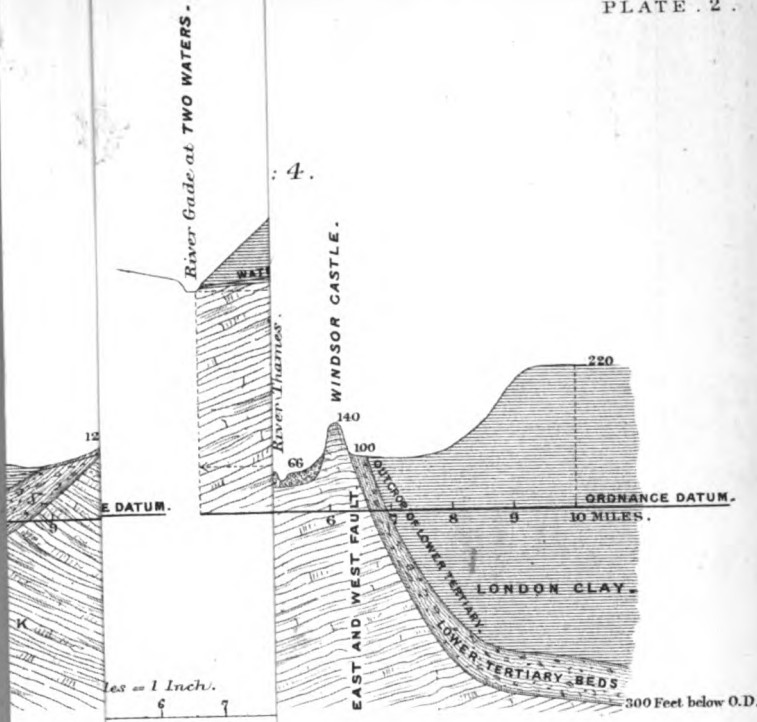

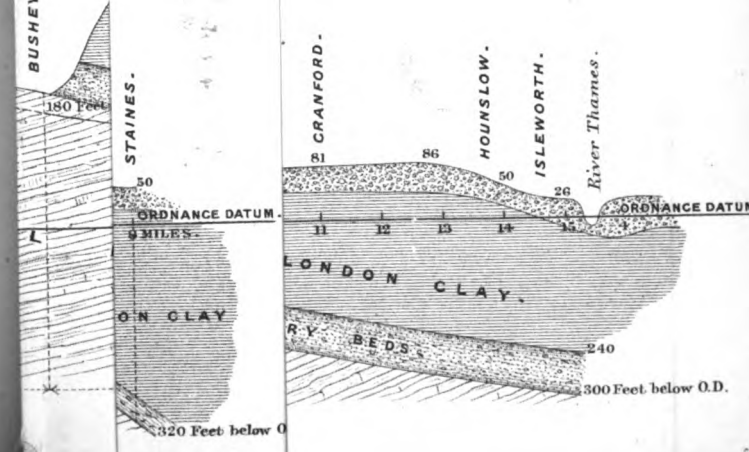

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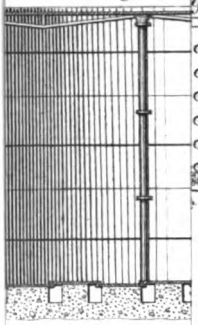

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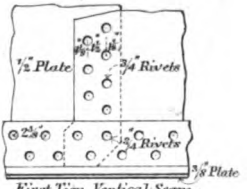
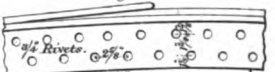
Fig:10.



First Tier, Vertical Seam and Riveting of bottom to side.

Fig: 11.



Riveting bottom to side.

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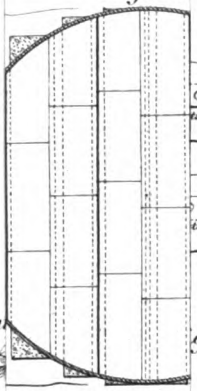

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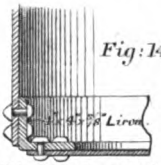

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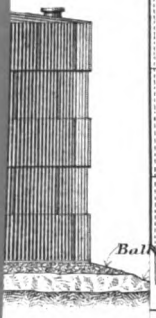

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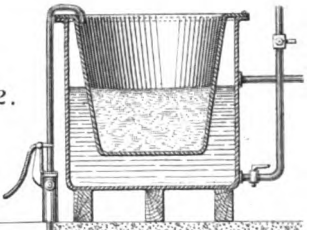

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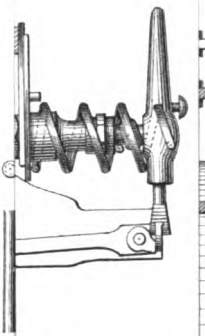

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Fig: 15

Fig: 29.

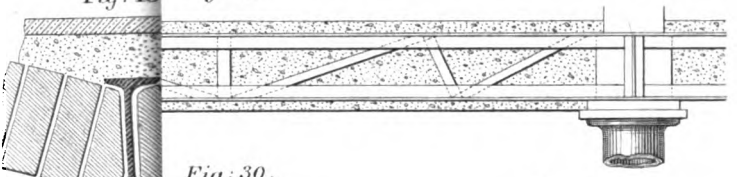
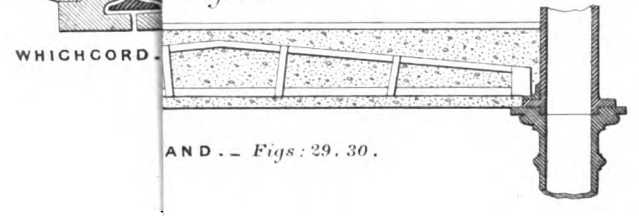


Fig: 30.



WHICHCORD.

AND.— *Figs: 29, 30.*

Fig: 31.

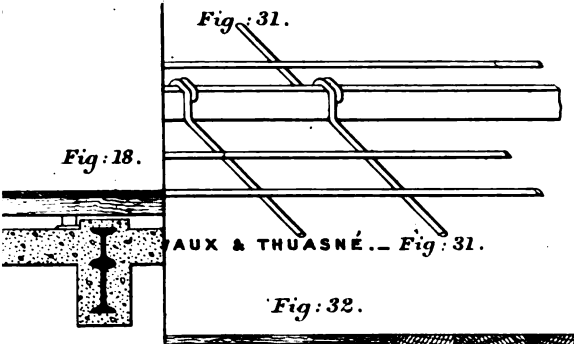


Fig: 18.

AUX & THUASNÉ.— *Fig: 31.*

Fig: 32.

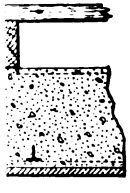


Fig: 33.

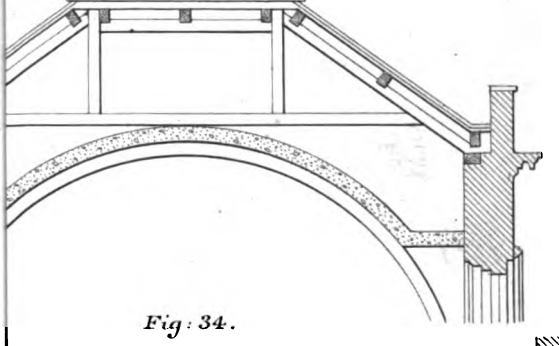
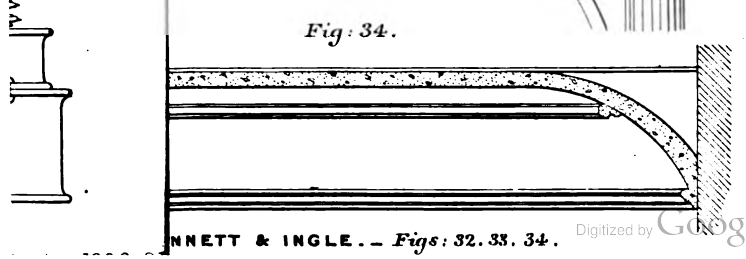


Fig: 34.



NNETT & INGLE.— *Figs: 32. 33. 34.*

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Fig: 67.

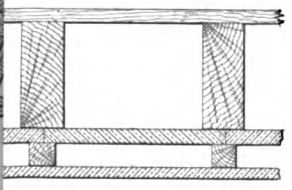
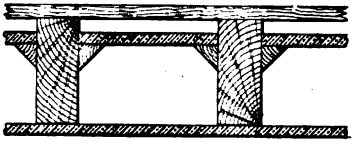
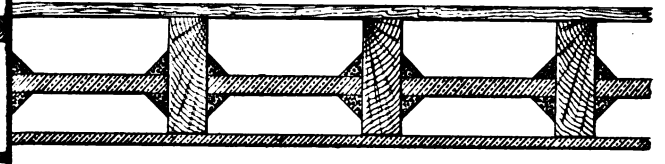


Fig: 68.



ANDERSON. — *Figs: 67. 68.*

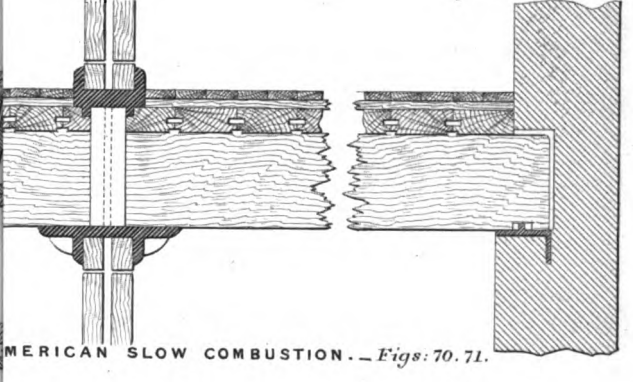
Fig: 69.



WILKINSON. — *Fig: 69.*

Fig: 70.

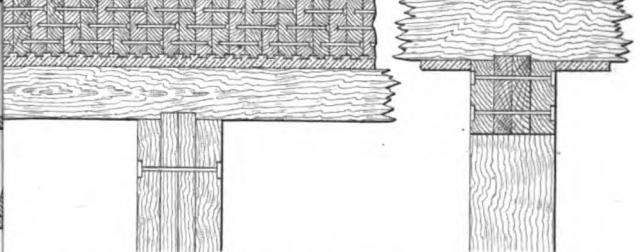
Fig: 71.



MERICAN SLOW COMBUSTION. — *Figs: 70. 71.*

Fig: 72.

Fig: 73.



54. 55 EVANS & SWAIN. — *Figs: 72. 73.*

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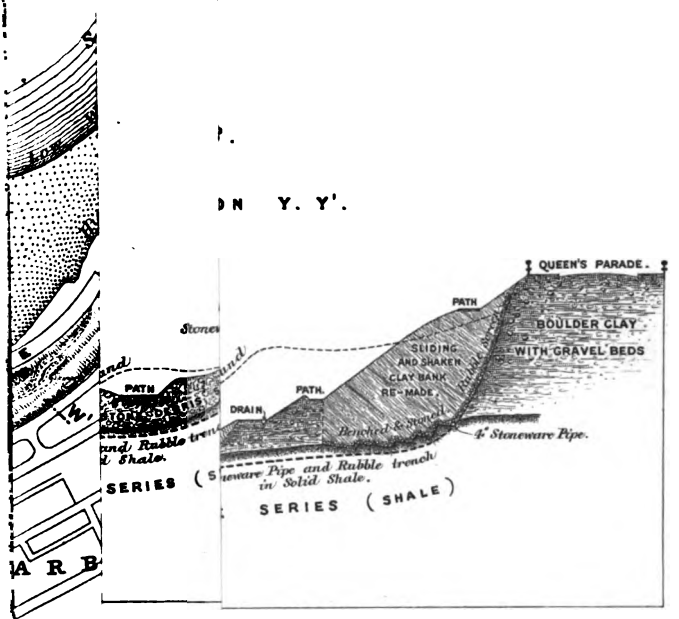

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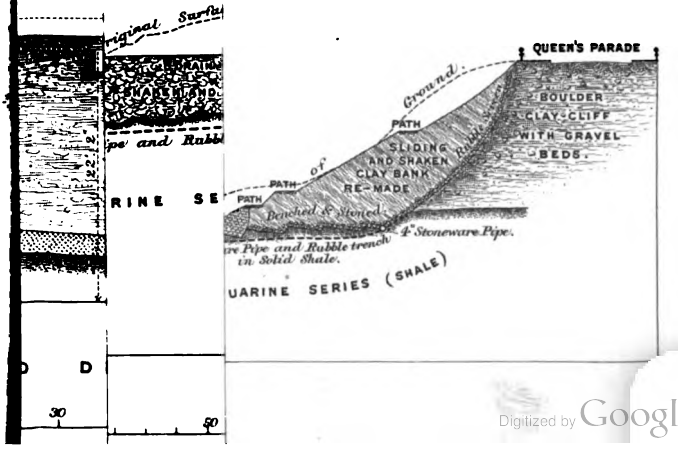

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